THE GEOLOGY OF THE SOUTH COAST OF NEW SOUTH WALES.

Part i. The Palaeozoic Geology of the Moruya District.

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(Plates xv-xviii; four Text-figures.)

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(1) Introduction and Previous Records.

The area under consideration is situated on the south coast of New South Wales, two hundred miles south of Sydney. The town of Moruya, situated five miles from the mouth of the Moruya or Deua River, is the centre of a large dairy-farming district, and has recently been brought under public notice by the reopening of "granite" quarries by the firm of Dorman, Long and Company, Limited, in order to supply stone for the building of the Sydney Harbour Bridge.

No detailed geological work on this district has hitherto been attempted, although one finds references to the Moruya district in several reports of the Departments of Mines and Agriculture of this State. An analysis of Moruya granite was published by Professor A. Liversidge in his "Minerals of New South Wales", and is quoted in a paper by W. Anderson (1892) on "The General Geology of the South Coast", where a very brief account of the geology of the Moruya District is recorded.

Further reference is made by Dr. H. I. Jensen in a paper on "The Soils of New South Wales", and short reports of an economic nature have been made by L. F. Harper (1910), and T. L. Willan, B.Sc. (1923).

(2) General Geology.

The general geological structure of the district might be described briefly as that of a folded and faulted series of early Palaeozoic sediments, which has been intruded by a series of plutonic rocks, ranging from gabbro to biotite-granite. Several systems of igneous dykes intersect the whole region.

Conglomerates, which are supposed to be of Devonian age, form a capping over the steeply inclined older sediments in a few places, and Tertiary sediments and basalts cover considerable areas within a few miles of the present coast-line.

The Post-Tertiary history includes the evolution of the present physiography, with the accumulation of quantities of alluvium, recent sands, and shell deposits along the rivers, coastal lagoons and low-lying coastal areas.

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* This work was commenced when the writer held the position of Demonstrator in Geology at the University of Sydney.

It is proposed to give in this paper an account of the Palaeozoic Geology of the Moruya District, and at a later date to deal with the Tertiary and Post-Tertiary History of the South Coast.

(3) The Sedimentary Series.

The older sedimentary rocks of the district have been subjected to a certain amount of regional metamorphism, but still show evidence that they were originally fine-grained sediments, which were deposited under fairly stillwater conditions. They are represented now by thin-bedded quartzites and silky, purple or greenish-grey slates, some of which possess well-developed cleavage. On the road to Araluen, eleven miles from Moruya, the slates and interbedded quartzites dip to the west at 43° and contain distinct ripple marks; the ridges of the ripples are about two and a half inches apart and run east and west, thus indicating a shallow water origin for the sediments.

The only traces of organic remains yet known in this series occur in sandy purple slates on the northern bank of the Deua River, about 22 miles by road from Moruya. These fossils are not well preserved, but, in the opinion of Mr. Dun, Government Palaeontologist, they are certainly organic, and are probably the carapaces of crustaceans.

For convenience these old, altered sediments will be referred to as "slates", or the "slate series", it being understood that the term includes all the slates, phyllites and thin-bedded quartzites of Pre-Devonian age.

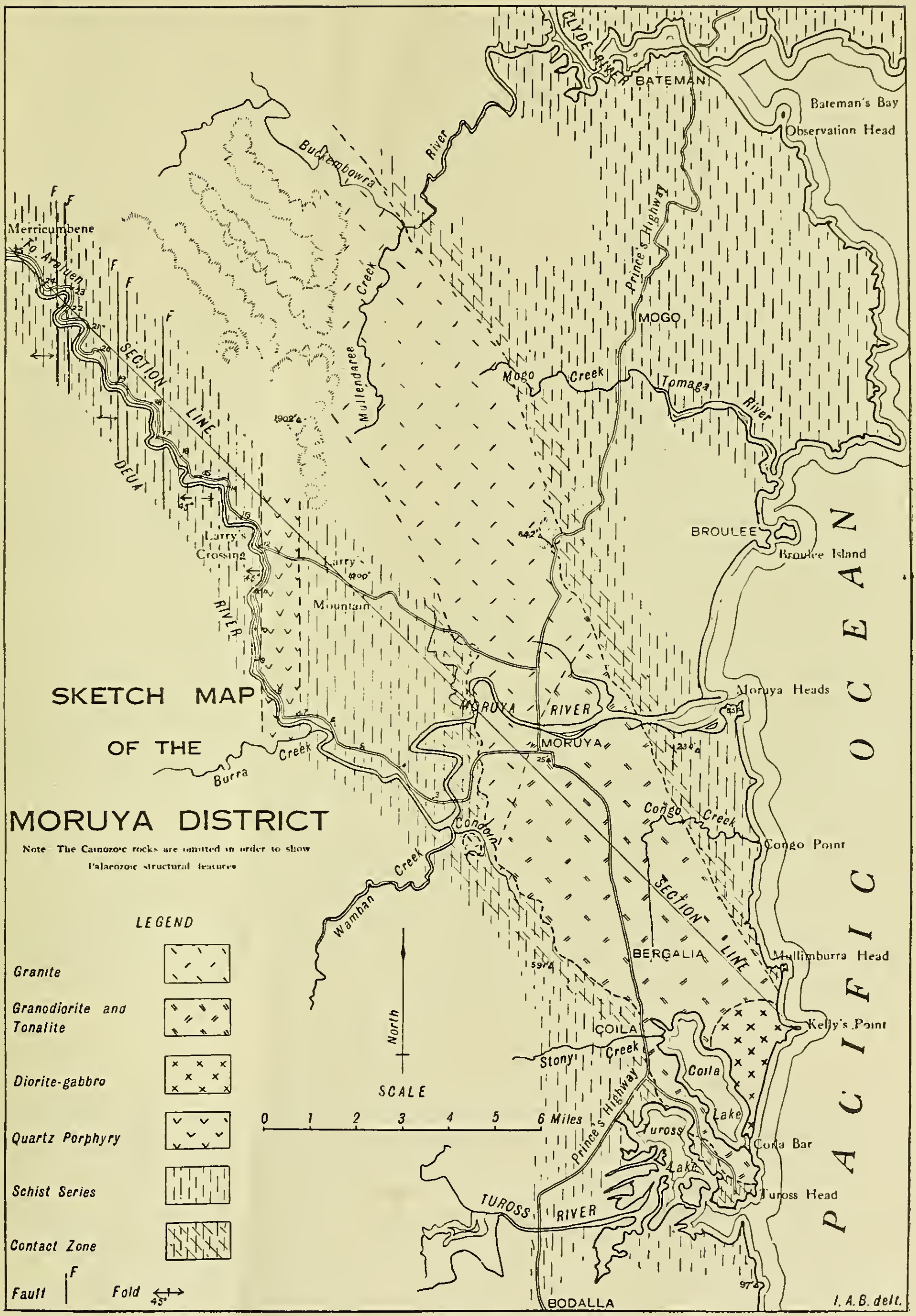
These slates form part of a series, which extends from the head of the Clyde River in a southerly direction for about ninety miles to the Brogo-Tathra district, and from the coast in a westerly direction for about thirty miles to the Main Divide. At intervals they are interrupted by intrusions of igneous rocks consisting of granites, monzonites and more basic types, which outcrop at Moruya, Bodalla, Mount Dromedary, Cobargo, Brogo and Bega along the coast, and several other places further inland. The slates are also partly covered by later Palaeozoic and Cainozoic sediments and basalts.

The geological age of the series has not yet been proved, as up to the present there is no record of any fossils having been found in them. Specimens of *Favosites* were discovered by W. Anderson (1892) in limestone at Bendithera, nearly thirty miles west of Moruya, at the head of the Deua River, and an Upper Silurian age is assigned to these beds. Unfortunately, the relation of the limestone to the slates to the east is not known at the present time.

In 1851 the Rev. W. B. Clarke examined the granites and slates in the neighbourhood of Araluen and lower down the Deua River, and later examined the Clyde Valley and Yalwal Districts. He evidently considered the slates to be Silurian in age, apparently basing his opinion on the lithological character of the rocks, and their similarity to Silurian rocks on the western side of the Main Divide.

Later writers have accepted this provisional classification, and one finds in a number of reports on mining in the southern goldfields, references to the slate series as of possibly Silurian age.

For the purpose of soil classification, Dr. H. I. Jensen (1910) has divided the series into two parts, (*a*) the Nelligen Schists, extending from near Termeil to the south of Bodalla, and (*b*) the Narira Schists, extending from seven miles south of Bodalla to Brogo, but this division is somewhat misleading from a geological standpoint.


SKETCH MAP
OF THE
MORUYA DISTRICT
Note The Cainozoic rocks are omitted in order to show Palaeozoic structural features
LEGEND
Granite
Granodiorite and Tonalite
Diorite-gabbro
Quartz Porphyry
Schist Series
Contact Zone
Fault
F
Fold
45°
North
SCALE
0
1
2
3
4
5
6 Miles
PACIFIC OCEAN
BATEMAN
Bateman's Bay
Observation Head
Clyde River
Buckenbowra
River
Creek
Mullendaree
Merricumbene
To Araluen
DEUA
RIVER
SECTION LINE
Larry's Crossing
Larry Mountain
1902'
842'
Mogo Creek
MOGO
Prince's Highway
Tomaga River
BROULEE
Broulee Island
Moruya Heads
MORUYA RIVER
MORUYA
Burra Creek
Wamban Creek
Condon
Congo Creek
Congo Point
BERGALIA
Mullimburra Head
Kelly's Point
COILA
Stony Creek
Coila Lake
Coila Bar
Tuross Lake
Tuross Head
TUROSS RIVER
BODALLA
I. A. B. delt.

Text-fig. 1.

Within a radius of approximately thirty miles of Moruya, the slates consist of a folded series, which have a constant direction of strike, running within a few degrees of north and south. Small exposures of the slates, such as occur in road cuttings along the Prince's Highway, show only beds which are apparently vertical; larger exposures, however, all clearly show that the series has been subjected to meridional folding, which has been very intense over the eastern portion, gradually diminishing in intensity to the west. This is illustrated by the cliff-sections east of the town of Bateman, on Bateman's Bay, the sea-cliffs near the mouth of the Tomaga River, and the section revealed by the erosion of the Deua River between Moruya and Araluen.

Faulting has accompanied or closely followed the folding along parallel axes. This fact, together with the complete absence of a fossil-horizon*, and the more or less uniform nature of the sediments, makes it impossible to estimate the thickness of the series outcropping over such a large area.

A belt of quartz-porphyry, more than one mile in width, occurs about seven miles west of Moruya and trends in a northerly direction. It appears to be intrusive along one of the fault-planes. The porphyry is inclined to be tuffaceous towards both eastern and western boundaries, containing small angular fragments of felsitic rocks: towards the west it has the appearance of being interbedded with vertical bands of slate. A narrow band of similar porphyry occurs in a fault-zone through hardened sandstone and reddish-purple slates, between 21 and 22 miles along the road from Moruya to Araluen. There seems little doubt that the porphyry is really intrusive into the slate series.

As previously stated, the folding is most intense in the rocks which lie to the east. In the neighbourhood of Observation Point, east of Bateman, the rocks consist of crushed conglomerates and contorted, banded quartzites and slates, which are faulted in a meridional direction. These extend to the headland known as the "Hanging Rock", about a mile from Bateman. Half a mile of shell-banks, raised only a few feet above sea-level, separates this outcrop from the typical greenish-grey slates of Bateman, which appear to belong to a series younger than that of the crushed conglomerates to the east. No actual junction between the two series has been seen by the writer, but observations on the rocks between Bodalla and Narooma suggest a similar division into two series, without any marked angular unconformity, the older lying to the east of the younger.

The occurrence of small veins of turquoise in the vicinity of Bodalla and Eurobodalla as recorded by Curran (1896, p. 252) has been taken as an indication that these rocks are Ordovician, but as yet there is no definite evidence as to whether the slates are Ordovician or Silurian.

(4) THE IGNEOUS SERIES.

(i) *Occurrence and Field Relations.*

An examination of the accompanying geological map of the Moruya District (Plate xv) reveals the fact that the plutonic rocks outcrop over a belt some three and a half miles in width, extending from the neighbourhood of the coast north of Tuross Head in a north-north-westerly direction through Moruya and out to the west of Mogo. The writer was unable to complete the mapping in this direction on account of the mountainous and inaccessible nature of the country, but has some reason for believing that the mass is connected with the mountain granites east of Araluen.

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* The discovery by the writer, subsequent to the completion of this paper, of *Spirifer disjuncta* in quartzites at Coondella, about 12 miles west of Moruya, proves the presence of Devonian rocks, and there is a possibility that the quartzite series immediately west of the quartz porphyry may be of this age.

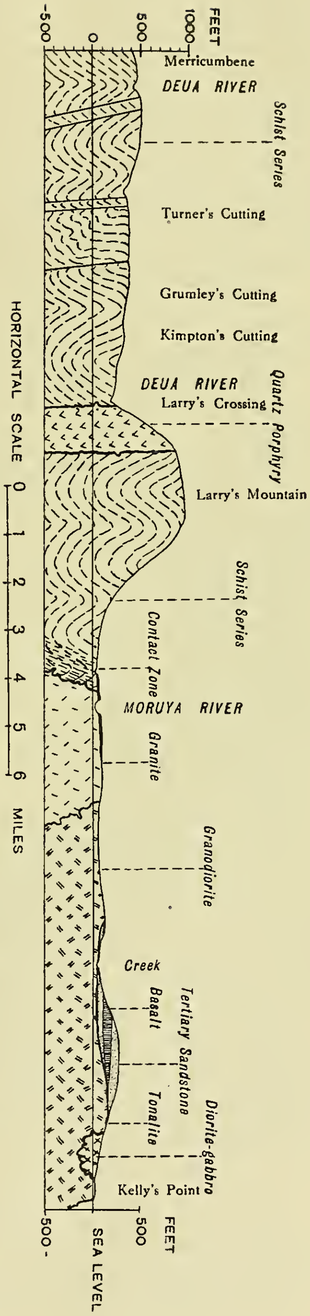
The general directions of the eastern and western boundaries of this mass are similar, consideration being given to the fact that it is in part covered by newer formations, including Tertiary sediments and basalts between Coila and Congo Point, and more recent alluvium over the flats of the Moruya River and Congo Creek. This feature may be more clearly seen in the modified map given in Text-figure 1, where the Cainozoic formations are omitted.

The occurrence of granitic rock has quite a marked effect on the topography, producing gently undulating country rarely rising to an altitude of 200 feet on the coastal portion of the area, whilst the adjacent steeply-inclined slates and schists produce rough, hilly country showing very much greater relief. This feature is well-illustrated near the Beashel trigonometrical station, about a mile west of Bergalia, where the contact slate rises to an altitude of 600 feet above sea-level, within less than half a mile of the low-lying granite area, quite close to sea-level. The slate ridges west of Moruya rise to over 2,000 feet.

In like manner the differences in the resultant soil have produced a variation in the vegetation, which is quite striking even to the casual observer. The slates weather to rather poor, siliceous soils, although they support a number of valuable timbers. *Eucalyptus maculata* (spotted gum) is characteristic, and sometimes attains a great height; a magnificent specimen is growing near the 6-mile peg south of Bodalla. *Eucalyptus corymbosa* (bloodwood), *E. pilularis* (blackbutt), *E. eugenioides* (stringybark), and occasionally *E. siderophloia* (ironbark) flourish on the slate soil, with patches of *Acacia* (?) *penninervis* (myall) and *Backhousia* (myrtle) in sheltered positions.

The burrawangs, *Macrozamia*, are very abundant on the slate soil and are practically absent from the granitic soil, thus forming a good index of the character of the underlying rock.

E. (?) *hemiphloia* (box) and *Angophora* (?) *subvelutina* (apple) occur on the granitic soils, with some *E. siderophloia* (ironbark) and *E. eugenioides* (stringybark).



Text-fig. 2.—Generalized geological section from Merricumbene to Kelly's Point, Moruya district.

From an agricultural viewpoint the slates are practically useless, as the soil is too shallow, except where it has been collected along river-flats, whereas the soil derived from the igneous rocks is suitable for dairy-farming. For this reason the chief centres of settlement along this part of the coast are on outcrops of igneous rocks, which are separated by large tracts of slate country, inhabited only by timber-getters and occasional miners.

The igneous rocks in the Moruya district consist of a series ranging from gabbro, through tonalite (quartz-diorite) and granodiorite to biotite-granite, with associated dykes of porphyry and aplite. The intermediate plutonic rocks, the tonalite and granodiorite, outcrop over the greater portion of the area mapped in detail (Plate xv), while the gabbros occur to the south-east, and the acid granites occur to the north-west of the intermediate series.

It will be shown (p. 184) that the igneous series as a whole is intrusive into the slates, but it is overlain by Tertiary sediments and basalts between Coila and Congo Head, and by alluvium along the river flats, as shown on the map.

The individual members of the series, the gabbro, tonalite-granodiorite, and biotite-granite, are fairly uniform in composition, and do not grade into one another.

The field relations between the gabbros and tonalite may be studied along the sea coast at Kelly's Point, and at the head to the north, known locally as the Clear Hill Point, about 10 miles south-east of Moruya, where there are excellent exposures of the contact. Kelly's Point is an exposed headland, which runs out to sea for some distance at right angles to the general trend of the coastline, and is of intense interest, not only on account of the relations of the plutonic rocks, but also because of the occurrence of a series of peculiar dyke-rocks which will be described later. A geological sketch-map of the most easterly portion of the Point is given in Text-figure 3. The tonalite contains numerous dark-coloured inclusions of igneous rocks, similar to the "basic segregations" occurring in the granodiorite. At its junction with the diorite-gabbro, the tonalite has sent off numerous sharply-defined little apophyses into the invaded rock, leaving no doubt as to its later intrusion.

The tonalite and granodiorite appear to grade into one another, and outcrop over part of the Tuross Peninsula, and from Bergalia to the township of Moruya.

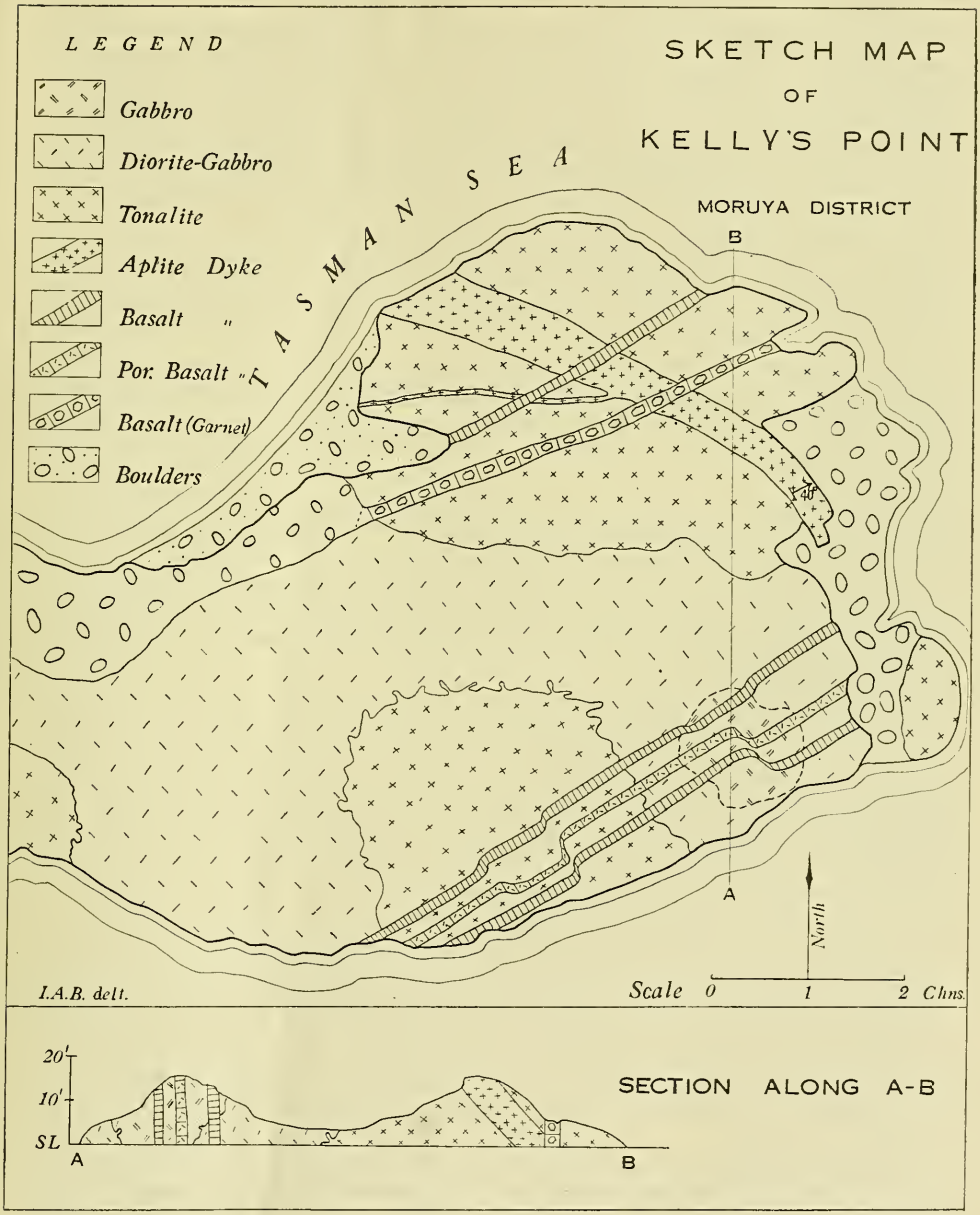
The granodiorite and the biotite-granite are lithologically distinct: the granite forms an isolated outcrop in the neighbourhood of Condoin Creek and occurs also in the main belt to the north and north-west of Moruya. The field relations between the granodiorite and granite are obscured by alluvium and cultivation patches, but as deposits of gold and silver-bearing arsenical-pyrites are associated only with the biotite-granites, it is considered that the granite is most probably of later formation than the granodiorite.

Several systems of dykes intersect the whole region, and are described in detail below. In the intermediate plutonic series there occur numerous dark inclusions, some of which are fragments of the slate series and others are igneous rocks, whose origin is probably co-magmatic with that of the granodiorite.

(ii) *Structures in the Plutonic Rocks.*

There are certain structures in the igneous mass itself which show evidence of crustal strains operating about the time of its intrusion. These include (*a*) jointing, and (*b*) "rift and grain" structure.

(*a*) *Jointing.*—At Pollwambra Mountain, five miles north of Moruya, vertical jointing is very distinct in a direction E. 10° N. At the quarries at present being worked by Dorman, Long and Co. vertical joints occur in two principal directions, E. 10° N. and N. 20° W., whilst jointing in a third direction N. 50° E. is not so well developed and is parallel to a dyke of a basaltic nature, which for a time marked



Text-fig. 3.

the eastern boundary of the smaller quarry opened up to the west of the old main quarry.

Aplitic veins less than one inch in thickness occur parallel to minor joints dipping at 45° to the north-east in Dorman, Long's quarry, and at 50° to the south-west in Louttit's quarry, on the southern side of the River.

Locally, a kind of sheet structure is developed in the main quarry owing to the presence of a system of joints which are more or less horizontal, with a downward sagging in the centre. This system is not parallel to the present land surface, but may bear some relation to the cooling-surface of the granodiorite magma.

The only other good exposures showing jointing are in the south-east portion of the mass. At Kelly's Point the dominant jointing is in a direction E. 15° N., which is also the direction of strike of the majority of dykes here. Another set of joints runs about at right angles to this direction. Between here and Tuross Head most of the dykes, following the set of principal joints, are running in the direction E. 15° N., while west of Kelly's Point, on the shore of Coila Lake and in the neighbourhood of Bergalia, the average direction of strike varies from E. to E. 10° S.

A few less important dykes run approximately at right angles to this direction, including two narrow basaltic dykes in the western part of Kelly's Point, an aplite dyke in Por. 276, Parish of Congo, between Coila Lake and the sea, and several dyke channels through quartz-schists at Du Ross (Mullimburra) Point, which strike N. 26° W.

Thus it is evident that the chief joint system is approximately at right angles to the direction of elongation of the batholith, while jointing parallel to the direction of elongation is less perfectly developed.

(*b*) *Rift and Grain.*—The other internal evidence of tectonic stress lies in the development of the structures known as rift and grain, which are intimately associated with the slight though marked parallel arrangement of certain of the constituent minerals.

The phenomenon of "*rift*" and "*grain*" is one which has attracted the notice of geologists who have been working in granite areas in other parts of the world, for the last hundred and fifty years. It is found that usually in granitic rocks there is a certain direction, either approximately vertical or horizontal, along which the rock splits more readily than in any other direction. This direction is known as the "rift". At right angles to this there is another direction of splitting with relative ease, which is known as the "grain", whilst the direction at right angles to both "rift" and "grain" is called the "hard way".

The results of careful observations on the "rift" and "grain" in granites of the States of New England, North America, have been recorded by T. Nelson Dale (1923), who gives a detailed bibliography and a summary on rift and grain structures. It is shown that cracks through the felspar and quartz occur in the directions of the rift and grain, as well as planes of gas or liquid inclusions through quartz, pointing to an intimate relation between the arrangement of inclusions and the rift and grain structure. Moreover, porphyritic felspars may be arranged with their long axes parallel to the rift and grain, or mica plates may occur all parallel to the rift.

Sufficient has been stated to show that these structures are an expression of crustal strains and stresses during or after the consolidation of the magma, and a study of their directions may have some bearing on the tectonic history of the area.

In the Moruya district it is found that the slight parallel structure developed in the more acid members of the igneous series, is due to the parallel arrangement of the flakes of biotite and the elongation of the hornblende (if present) and plagioclase crystals in one direction in this plane. This feature is most pronounced along the eastern boundary of the batholith. At the "granite" quarries east of Moruya, the exposed granodiorite shows that this structure is parallel to the rift, which is vertical, and runs in a north-north-westerly direction. The grain is horizontal. As yet no oriented microsections are available, but some random sections of the granodiorite and granite certainly do show continuous parallel cracks extending across quartz and felspar grains and also parallel strings of tiny inclusions continuing across a number of optically independent grains of quartz, which in all probability are parallel to the rift, as determined by Dale.

(iii) *Petrography of the Plutonic Rocks.*

A large number of specimens of the plutonic rocks have been collected from all parts of the area, and have been examined in detail, and a series of chemical analyses of representatives of the chief rock-types has been carried out.

The numbers M 123, etc., refer to the specimens in the writer's collection, which has been placed in the Geological Museum of the University of Sydney.

Biotite-Granite.

The most acid members of the plutonic series are the biotite-granites occurring to the north and west of Moruya.

The granite exposed along the main road (the Prince's Highway) five miles north of Moruya, is aplitic, the rock near the actual contact with the slates, M 337, being a white crumbly graphic-granite, which powders with a blow of the hammer, and consisting of quartz and altered orthoclase with the merest trace of biotite.

Farther away from the contact is a pinkish-grey variety of granite, a medium-grained rock that has suffered considerable alteration. Under the microscope it is seen to consist of quartz and orthoclase chiefly, with some acid plagioclase and altered biotite. A small amount of muscovite is present, partly intergrown with biotite, and partly as a decomposition product of the potash-felspar. Fracture and granulation are evidences of mechanical strain.

About half a mile from the contact a more normal granite appears, which is medium-grained, and grey in colour, with massive texture. In the handspecimen, white felspar, quartz and biotite are visible. Under the microscope the rock shows a granitic texture, and is seen to consist of quartz, orthoclase, oligoclase, and microperthite, with biotite and a very small amount of muscovite, some of which is of secondary origin. Some zircon occurs in the biotite. This rock still shows signs of fracture and granulation.

About a mile west of Moruya, on the south bank of the River, the granite contains a greater amount of orthoclase and microperthite. It is interesting to note that neither in the handspecimen nor under the microscope can this rock (M 320) be distinguished from the granite outcropping at Bunnair Swamp, Conjola, about seventy miles to the north of Moruya. It is also similar to the granite outcropping a couple of miles south of Bodalla (M 398), as well as the granite from the Buckembowra district, near Nelligen (M 270).

The isolated outcrop of granite in the neighbourhood of Condoin Creek, south-west of Moruya, consists essentially of a similar acid biotite-granite (M 232), much of which has suffered considerable alteration on account of pneumatolysis, with the introduction of ores of silver, gold, arsenic and other metals. In several localities there is a very interesting metasomatic replacement of the biotite by gold-bearing arsenical-pyrites (M 242, M 243, Baker's Shaft).

A good exposure of fresh, typical biotite-granite occurs near Heffernan's property, Portion 32, Parish of Mogendoura, on the road from Moruya to Araluen over Larry's Mountain. In the handspecimen (M 343) it appears to be a massive grey granite, medium to fine, and even-grained, consisting of quartz, white felspar and biotite.

Under the microscope it is seen to be hypidiomorphic to allotriomorphic granular, with a marked tendency to monzonitic fabric, and consists of quartz, plagioclase, orthoclase (including microperthite) and biotite, with very small amounts of apatite and zircon enclosed in the biotite.

The quartz occurs as allotriomorphic grains, either between the plagioclase crystals or else included in plates of orthoclase. It contains numerous tiny liquid inclusions, some of which contain a gaseous bubble, and which are arranged in definite lines that are continuous across a number of optically independent quartz grains. There is little doubt that this is an expression of rift and grain structure in the rock.

The plagioclase forms more or less idiomorphic prismatic crystals, about 2 mm. in diameter. It is slightly zoned and shows twinning after Carlsbad, albite and pericline laws, and is oligoclase of the composition $Ab_{78}An_{22}$.

Orthoclase is present interstitially, and as allotriomorphic plates, which enclose crystals and grains of all the other minerals, as it has been the last mineral to crystallize out, giving the rock a kind of monzonitic fabric. In most of the orthoclase there is a slight development of microperthite, as though the soda-felspar had separated out along one of the cleavage directions of the potash-felspar.

The biotite occurs as allotriomorphic flakes rarely exceeding 1·5 mm. in diameter. It has a brown colour, is strongly pleochroic, and contains small crystals of apatite and smaller needles of zircon surrounded by a pleochroic halo. A section of the rock is shown on Plate xvii, fig. i.

The chemical analysis of this rock appears below.

	Wt. p.c.	Mol. Ratios.
SiO_2	70·78	1·180
Al_2O_3	15·77	0·155
Fe_2O_3	0·69	0·004
FeO	2·44	0·034
MgO	0·72	0·018
CaO	2·53	0·045
Na_2O	2·88	0·047
K_2O	2·44	0·026
H_2O + ...	0·50	—
H_2O −	0·06	—
TiO_2	0·45	0·005
P_2O_5	0·25	0·001
MnO	0·08	0·001
Total	99·59	
Sp. Gr. ...	2·688	

Norm.	
Quartz	36·84
Orthoclase	14·46
Albite	24·63
Anorthite	11·68
Corundum	4·08
Hypersthene	5·23
Magnetite	0·93
Ilmenite	0·76
Apatite	0·34

Biotite-Granite, Por. 32, Par. Mogendoura, Moruya District. Anal. I.A.B. Magmatic name: Alsbachose, near Tehamose. [1, 3′, 2(3), (3)4.]

Granodiorite and Quartz-Diorite.

The granodiorites and quartz-diorites outcrop over the area extending from a short distance north of Moruya, to a point about half a mile north of Tuross Head.

A large number of specimens has been collected from all parts of the area, more than thirty of which have been sectioned and three chemically analysed. Whereas the granite occurring to the north-west is characterized by the presence of quartz, acid plagioclase (oligoclase), orthoclase, microperthite and biotite, the granodiorite and quartz-diorite consist essentially of more basic plagioclase (andesine), quartz, hornblende, biotite and very subordinate orthoclase which is merely interstitial.

There are slight differences in the texture and grainsize of different specimens of the rock, as well as minor variations in the relative proportions of the minerals present, giving differences in the body colour of the rock. In general, the rock appears to be slightly more acid in the northern and western portions of the area and may be called granodiorite, whereas the eastern and southern portions appear to be more basic, and may be designated quartz-diorite or tonalite.

Evidence of compressive crustal strain is most marked along the eastern border of the outcrop, where slight parallel arrangement of the minerals is obvious, and the dark inclusions or "basic segregations" are most abundant.

One of the best exposures of typical granodiorite is at the quarries on the left bank of the Moruya River, two miles below the town. Commercially, the stone is known as "granite", and in the past has been used in a number of the principal buildings of Sydney, including the G.P.O. and the Customs House, the material having been taken partly from these quarries, and partly from Louttit's quarry situated on the opposite bank of the river, rather nearer the mouth.

A finer grained and slightly abnormal type of granodiorite has been quarried for local purposes in portion 48, parish of Moruya, about a mile south-west of the town.

In the handspecimen, the typical rock at Dorman Long's quarry, when free of "basic segregations", is light grey in colour, and shows slight parallel arrangement of the minerals. It is evengrained, the average grainsize being 5 or 6 mm. The minerals appear to be plagioclase, quartz, biotite, hornblende and occasionally iron pyrites.

Under the microscope, the grainsize is seen to be variable, ranging from 1 mm. to 6 mm., as each of the quartz "grains" as seen in the handspecimens, actually consists of a number of smaller grains. The fabric is hypidiomorphic granular. The microscope reveals also the presence of a little orthoclase, with apatite, sphene, zircon, magnetite, ilmenite and iron pyrites as accessory minerals.

Strain is indicated by the parallel arrangement of the crystals, by fracture and granulation of the felspar and quartz grains, and by bending of the biotite.

The plagioclase is andesine, $Ab_{68}An_{32}$, occurring as subidiomorphic tabular crystals, showing twinning after Carlsbad, albite and pericline laws. It appears to have crystallized early in the cooling history of the magma, or at least to have pushed aside the grains of ferromagnesian minerals. In crush zones indicated by fracture and granulation, there is a slight development of myrmekite, where the plagioclase is in contact with orthoclase.

Quartz occurs as irregular grains between the felspar crystals, and is quite allotriomorphic. It contains tiny liquid and gas inclusions.

The hornblende crystals are prismatic, and are about 3 mm. in width, and 7 mm. in length. The mineral is dark green, and strongly pleochroic, and shows

	I.	Ia.	II.	IIa.	III.	IIIa.	IV.	IVa.	V.	Va.
Sp. Gr.	2·729	—	—	—	2·722	—	2·711	—	2·705	—
SiO_2	65·72	1·095	65·44	1·091	64·04	1·067	65·36	1·089	64·20	1·070
Al_2O_3	17·63	0·173	17·73	0·174	15·58	0·153	16·37	0·161	16·94	0·166
Fe_2O_3	0·42	0·003	1·17	0·008	0·80	0·005	1·80	0·011	2·00	0·012
FeO	2·80	0·039	3·45	0·048	4·47	0·062	2·68	0·038	2·44	0·034
MgO	1·73	0·043	1·45	0·036	2·64	0·066	1·81	0·045	2·03	0·051
CaO	4·36	0·078	3·99	0·071	3·52	0·063	3·82	0·068	4·56	0·081
Na_2O	3·14	0·051	3·58	0·058	2·42	0·039	3·40	0·055	4·00	0·064
K_2O	2·12	0·022	2·17	0·023	2·80	0·030	3·75	0·039	2·76	0·029
H_2O+	1·03	—	1·18	—	2·25	—	0·33	—	0·47	—
H_2O-	0·06	—	—	—	0·38	—	0·09	—	0·14	—
CO_2	abs.	—	—	—	abs.	—	abs.	—	0·01	—
TiO_2	0·41	0·005	0·39	0·005	0·80	0·010	0·36	0·005	0·39	0·005
ZrO_2	0·19	0·002	—	—	—	—	trace	—	abs.	—
P_2O_5	0·19	0·001	—	—	0·18	0·001	0·16	0·001	0·22	0·001
SO_3	—	—	—	—	—	—	abs.	—	0·12	—
Cl	—	—	—	—	trace	—	0·05	0·001	trace	—
F	—	—	—	—	—	—	0·14	0·008	—	—
S (FeS_2) ..	0·13	0·004	—	—	abs.	—	abs.	—	trace	—
Cr_2O_3	abs.	—	—	—	—	—	trace	—	trace	—
NiO, CoO ..	—	—	—	—	—	—	abs.	—	0·01	—
CuO	—	—	—	—	—	—	abs.	—	0·01	—
MnO	0·08	0·001	0·18	0·003	trace	—	0·16	0·002	0·07	0·001
BaO	abs.	—	—	—	—	—	0·14	0·001	0·02	—
SrO	trace	—	—	—	—	—	trace	—	trace	—
Li_2O	—	—	—	—	—	—	trace	—	abs.	—
TOTAL ..	100·01	—	100·73	—	99·88	—	100·42 0·07* 100·35	—	100·39	—

* O = F_2, Cl_2.

Columns Ia, IIa, etc., in this and succeeding tables give the molecular ratios.

The norms and C.I.P.W. classifications are as follow:—

	I.	II.	III.	IV.	V.
Quartz	25·92	23·34	25·14	19·20	17·52
Orthoclase	12·23	12·79	16·68	22·24	16·12
Albite	26·72	30·39	20·44	28·82	33·54
Anorthite	20·85	19·74	16·68	18·07	20·29
Corundum	2·55	2·24	2·45	—	—
Zircon	0·37	—	—	—	—
Diopside	—	—	—	—	1·14
Hypersthene	8·26	8·62	12·94	7·67	6·91
Magnetite	0·70	1·86	1·16	2·55	2·78
Ilmenite	0·76	0·76	1·52	0·76	0·76
Apatite	0·34	—	0·34	0·34	0·34
Pyrite	0·24	—	—	—	—

I. Granodiorite [Yellowstonose. I(II), 4, 3, 4], Dorman, Long and Coy.'s Quarry, Moruya. M.L.4, Parish Tomaga, Co. St. Vincent. Anal. I.A.B.

II. Tonalite [Yellowstonose. I(II), 4, 3, 4], Adamello, Tyrol. Anal. Z. Weyberg. *Neues Jahrbuch für Mineralogie*, 1912, p. 398. W.T., p. 262.

III. Granodiorite [Harzose. ″II, ″4, 3, 3], near Braemar House, Macedon Dist., Vict. *Geol. Surv. Vict.*, Bull. 24, 1912, p. 20. In W.T., p. 368, No. 79.

IV. "Blue Granite" [Amiatose. I(II), 4, (2)3, 3″], Tenterfield, New England, N.S.W. *Rec. Geol. Surv. N.S.W.*, 1905-9, pp. 203, 238. In W.T., p. 253.

V. "Sphene Granite" excluding orthoclase phenocrysts, Undercliffe, Wilson's Downfall, New England, N.S.W. [Yellowstonose. I(II), 4, ″3, 4]. *Rec. Geol. Surv. N.S.W.*, 1905-9, pp. 209, 238 (Norm re-calculated).

In Nos. II, III and IV the norms quoted are as given in Washington's Tables.

a tendency to crystallize with the biotite in such a way that the "c" crystallographic axis of the hornblende is parallel to the plane of (001) of the biotite.

Brown, pleochroic biotite is present as allotriomorphic flakes, about 2 mm. in diameter. It shows alteration to chloritic material, and more rarely to epidote and lenses of carbonates between the cleavage lamellae, such as that described by Iddings (1911, p. 494). It contains acicular apatite, and zircon surrounded by pleochroic haloes.

A small amount of orthoclase occurs interstitially.

Idiomorphic sphene and small amounts of iron ores are scattered through the rock.

The chemical analysis of a typical specimen of this rock (M 122) is given in column I (p. 162), and a photomicrograph of a thin section on Plate xvii, fig. 2.

Considering the analysis of the Moruya granodiorite, it is found that there is less orthoclase in the mode than shown in the norm, as the potash molecule goes to form biotite; also the plagioclase is not so basic as that indicated in the norm, as some of the lime silicate combines with the ferromagnesian silicate (the hypersthene of the norm) to form hornblende in the mode. The silica percentage is slightly below that of a true granite, and the alkali percentage also shows that the rock is related to the diorites, and may reasonably be called a granodiorite.

In Column II is quoted the analysis of a tonalite from Adamello, which is remarkably similar to that of the Moruya rock. Indeed, much of the granodiorite or quartz-diorite might appropriately be called "tonalite" as defined by Holmes (1920, pp. 227, 194) for mineralogical reasons also.

The analysis of a typical granodiorite from the Mount Macedon District, Victoria, is quoted in Column III to show the general similarity to the Moruya rock.

A study of the work on the New England granite by E. C. Andrews and other members of the staff of the Mines Department of New South Wales shows that magmatic differentiation has proceeded in New England in much the same way as it has done on a smaller scale in the Moruya District, and a number of similar rock types have been produced. For comparison with the granodiorite, the analyses of the "blue granite" from Tenterfield, and the Wilson's Downfall "sphene granite" without the orthoclase phenocrysts, are quoted in Columns IV and V.

Sphene, so characteristic of these rocks, is present also in the Moruya granodiorite and can be seen in the handspecimen, especially in the more basic types. The titania percentage is even higher than in the New England "sphene granite."

Similar granodiorites have recently been described by Buddington from Alaska (1927), and by Gillson from Idaho (1927).

Quartz-Diorite or *Tonalite.*

As stated above there are minor variations from the type, and the granodiorite grades almost imperceptibly into a true quartz-diorite or tonalite, such as that exposed at Kelly's Point.

Here it is sharply contrasted with the diorite-gabbro, which it intrudes. In the field it appears to be very similar to the granodiorite at the Moruya quarries, showing a similar parallel structure in the handspecimen, and containing abundant "basic segregations" and occasionally slaty inclusions, giving the rock a mottled appearance.

The quartz-diorite outcrops west of Mullimburra Head (Du Ross Pt.), at the Clear Hill Point, Kelly's Point, and the peninsula between Lake Coila and Lake Tuross, where it intrudes sandy micaceous schists. These localities are indicated on the accompanying map (Plate xv).

The handspecimen, when free of foreign inclusions, is dark grey, rather coarsely crystalline, and even grained, with a granitoid fabric, and appears to consist of white plagioclase, quartz, hornblende and biotite, with occasional grains of pyrites.

Under the microscope the rock is seen to have a hypidiomorphic granular fabric, very similar to that of the granodiorite, though there is less evidence of strain than in the rock at the quarry. The minerals present are plagioclase, quartz, hornblende and biotite, with subsidiary orthoclase, relatively abundant sphene, apatite, a little zircon and magnetite, and sometimes iron pyrites.

The plagioclase occurs as idiomorphic to subidiomorphic crystals about 2-3 mm. in diameter, slightly zoned, and commonly showing twinning after Carsbad, albite and pericline laws and sometimes after the Baveno law (M 175). It is andesine of the composition $Ab_{65}An_{35}$, slightly more basic than that of the granodiorite. In a few cases (*e.g.*, M 194, Clear Hill Pt.) the inner zone of felspar contains numerous small inclusions of hornblende, etc., some of which are optically continuous.

The quartz is not quite so abundant as in the granodiorite, but is otherwise similar, occurring as small allotriomorphic grains containing numerous tiny liquid inclusions, some of which contain movable gaseous bubbles.

The hornblende occurs as fairly large, well-formed crystals, green in colour and often simply twinned. It frequently occurs in intimate association with the biotite (M 217), crystallizing so that the basal plane of the biotite is parallel to the orthopinacoid of the hornblende.

Biotite is fairly abundant as small irregular grains, with some decomposition to chlorite and lenticular patches of carbonates.

A very small quantity of interstitial orthoclase is present in some sections and is almost negligible.

Apatite occurs as acicular crystals in the plagioclase and ferromagnesian minerals.

Sphene is particularly abundant as irregular grains and lozenge-shaped crystals associated with hornblende.

Iron pyrites and magnetite are both present in greater amount than in the granodiorite.

Types intermediate between the granodiorite at Moruya and the quartz-diorite or tonalite at Kelly's Point and Tuross, occur in the vicinity of Bergalia.

A specimen of quartz-diorite from Kelly's Point (M 175) was chosen for analysis, the result being given in Column I below.

	I.	Ia.	II.
SiO_2	61·44	1·024	59·47
Al_2O_3	17·61	0·173	16·52
Fe_2O_3	1·86	0·011	2·63
FeO	3·59	0·050	4·11
MgO	3·09	0·077	3·75
CaO	5·88	0·105	6·24
Na_2O	2·03	0·032	2·98
K_2O	1·03	0·012	1·93
H_2O+	1·17	—	1·39
H_2O-	0·10	—	
TiO_2	1·42	0·018	0·64
P_2O_5	0·33	0·002	—
MnO	0·09	0·001	0·08
TOTAL	99·64		100·00
Sp. Gr.	2·768		

Norm.	I.
Quartz	27·72
Orthoclase	6·67
Albite	16·77
Anorthite	27·24
Corundum	3·16
Hypersthene	10·60
Magnetite	2·55
Ilmenite	2·74
Apatite	0·67

I. Quartz-diorite (Tonalite), Kelly's Point, 10 miles S.E. of Moruya. Bandose nr. Tonalose ['II, (3)4, '4, 4]. Anal. I.A.B.

II. Average quartz-diorite (Osann, Washington), quoted from Daly, *Igneous Rocks*, 1914, p. 26, No. 43.

This rock is rather more basic than the granodiorite (M 122) given previously, containing more than 4% less silica, with an increase in lime, magnesia and iron, and a decrease in the amount of alkalis. The marked increase in the titania content is due to the abundance of sphene.

The analysis of the Moruya rock is very close to that of the average quartz-diorite given in Column II.

An abnormal variety of granodiorite occurs about a mile south-south-west of the Moruya Bridge, in the vicinity of Portions 48 and 49, Parish of Moruya, the property of P. Jeffery, and also on the road to Moruya Heads, in Portion 113.

The specimen described and figured by W. Anderson (1892) as being typical of the Moruya granite, is identical with this type. It is finer-grained than the typical granodiorite and is darker in colour, although it contains the same minerals: plagioclase, hornblende and biotite, with quartz, which is far less obvious in the handspecimen than in the coarser type. The rock is inclined to be porphyritic in plagioclase. It was thought that this was possibly a basic differentiate of the granodiorite, but actually its chemical composition is almost identical with that of the granodiorite (M 122).

In the field it is characterized by numerous small inclusions of darker rock, some rather angular, but many ellipsoidal in shape, having an indefinite boundary as though they had been partly digested by the host.

The peculiar habit of the quartz and plagioclase as seen under the microscope has been described by Anderson and may be seen in sections M 127 *a* and *b*. Numerous tiny rounded grains of quartz occur at the edge of the inner zone of plagioclase ($Ab_{65}An_{35}$), around which later plagioclase, of a slightly more acid variety, has been formed. The structure is not that of a true graphic intergrowth, although several grains of the quartz may extinguish simultaneously between crossed nicols. The structure seems to resemble somewhat the "quartz de corrosion" of French writers. Somewhat similar structures have been described by a number of writers, including Lacroix (1891, p. 156), Sederholm (1916, p. 64), Harker (1904, p. 186), Harker and Marr (1891, p. 278) and Andrews (1907, p. 215), but no satisfactory explanation of the phenomenon has been given. The fact that it occurs only in the neighbourhood of igneous inclusions gives some support to the idea that it is due to assimilation, and that the rock is really a hybrid. A photomicrograph of a thin section of the rock is shown on Plate xvii, fig. 3.

A very small amount of interstitial orthoclase is present.

The biotite and green hornblende both occur as ragged allotriomorphic grains about 1 mm. in diameter, which have frayed edges and contain inclusions of quartz, and occasionally felspar, giving a kind of poikilitic fabric, such as that seen in some diorites, and which is characteristic of many of the "basic segregations" in the granodiorite.

Small amounts of apatite, zircon and iron ores are scattered through the rock.

The analysis of this rock is given below.

	Wt. p.c.	Mol. Ratios.
SiO_2	65·83	1·097
Al_2O_3	16·44	0·161
Fe_2O_3	1·03	0·006
FeO	3·33	0·046
MgO	2·00	0·050
CaO	4·24	0·076
Na_2O	2·25	0·036
K_2O	3·40	0·036
$H_2O +$	0·67	—
$H_2O -$	0·10	—
TiO_2	0·78	0·009
P_2O_5	0·21	0·001
MnO	0·08	0·001
TOTAL ..	100·36	
Sp. Gr.	2·741	

Norm.	
Quartz	26·22
Orthoclase	20·02
Albite	18·86
Anorthite	20·29
Corundum	1·63
Hypersthene	9·22
Magnetite	1·39
Ilmenite	1·37
Apatite	0·34

Granodiorite, Por. 48, Parish of Moruya, Anal. I.A.B. Amiatose [I(II), 4, 3, 3].

The abundance of biotite and hornblende in the mode accounts for the rather large amount of potash calculated as orthoclase in the norm.

On comparing this analysis with that of the typical granodiorite a remarkable similarity will be observed. The relative increase in potash and iron percentages is due to the increase in the amount of biotite chiefly, which is reflected in the slightly greater specific gravity. The proportion K_2O : Na_2O places it in Amiatose next to Yellowstonose (M 122).

The slight abnormalities in the composition of this rock may have been caused by the assimilation of material such as that comprising the "basic segregations" described later, thus supporting the suggestion that, in a limited sense, the rock is a hybrid, although the dark inclusions may be co-magmatic.

Diorite-Gabbro and Hornblende-Gabbro.

The gabbro series outcrops over an area of about three square miles, between the northern part of Coila Lake and the sea-coast. To the north-west it is overlain by Tertiary sandstones and basalt, and on the south and east its outcrop is bounded by the lake or by sand-dunes. It has been intruded by the quartz-diorite as previously described, the contact being visible at Kelly's Point and at the Clear Hill Point, about a mile to the north.

In the field the diorite-gabbro appears as a dark grey holocrystalline rock of medium texture, which contains numerous segregation veins and patches, varying considerably in colour and texture. Also it is intruded by a large number of dyke rocks, including granite-aplite and pegmatite, hornblende-quartz-porphyrite, mica-lamprophyre, and an interesting variety of basaltic types, which will be described later.

By its colour and texture alone the diorite-gabbro, in the field, shows a very marked contrast with the granitic types previously described. In the hand-specimen, the rock has the appearance of a typical diorite, holocrystalline and medium-grained, consisting of black ferromagnesian mineral and white felspar in almost equal proportions. Some specimens show a small amount of iron pyrites and occasionally small well-formed crystals of sphene. The hornblende crystals show a certain amount of lustre-mottling, due to the poikilitic arrangement of the inclusions.

Under the microscope, the grainsize is seen to vary from 0·5 to 5·0 mm., the fabric is hypidiomorphic granular, with a tendency to poikilitic or subophitic.

The minerals present are chiefly hornblende and plagioclase, with very much smaller quantities of augite, biotite, orthoclase, apatite, sphene, iron pyrites and magnetite. Although the rock looks perfectly fresh in the handspecimen, small amounts of chlorite and calcite are also present.

The plagioclase is partly idiomorphic, but occurs also as small grains enclosed in the hornblende. It is well twinned, and consists chiefly of labradorite, $Ab_{47}A_{53}$, with a narrow outer zone of more acid andesine, $Ab_{65}An_{35}$.

In several instances there is a kind of graphic intergrowth of the plagioclase and the ferromagnesian minerals. One slide (M 278) shows a section of labradorite cut perpendicular to (010) and (001) in graphic intergrowth with colourless augite and brown hornblende, both partly idiomorphic, and also a skeletal form of iron ore. A photograph of this appears on Plate xviii, figs. 1 and 2.

Records of this kind of intergrowth are rare: the most similar case which has come to the notice of the writer is that of the graphic intergrowth of plagioclase and augite in a dolerite from King George Land, Antarctica, described by W. R. Browne (1923, p. 250). Iddings (Rock Minerals, p. 238) notes a graphic intergrowth between plagioclase and orthorhombic pyroxene, and Teall (1888, Plate xxiii) illustrates a graphic intergrowth of plagioclase and augite in a dolerite from Staffordshire. This rock is described by Allport (1874, p. 549). Harker (1909, p. 270) also gives references to somewhat similar graphic intergrowths.

The hornblende is perhaps the most interesting mineral in the rock. It occurs as large subidiomorphic plates, up to 5 mm. across, and also as small crystals, less than 1 mm. in diameter. The larger plates show marked colour-zoning, the central portion being itself irregularly zoned in shades of greenish-brown, while the outer zone is of a bluish-green colour, probably indicating the presence of a certain amount of soda. The mineral is strongly pleochroic. The natural colour of the mineral does not wholly mask the interference colour. Although many of the smaller crystals are idiomorphic, the larger ones are not quite so regular, and contain inclusions of plagioclase, biotite and augite, showing that the hornblende continued crystallizing until late in the cooling history of the magma.

There can be no doubt that the hornblende is a mineral of primary crystallization, and that it has been derived partly from the colourless augite, which occurs only as small grains less than 0·5 mm. in diameter surrounded by brownish hornblende. The boundaries are often indistinct, although the minerals may be in parallel intergrowth: the change from augite to hornblende has been accompanied by the liberation of some iron oxide, shown by the association of fine magnetite dust.

Biotite in small quantity occurs in association with hornblende and iron ore.

The ferromagnesian minerals in this rock, augite, brown hornblende, green hornblende and biotite, are a good illustration of the "reaction principle" of Bowen (1922, pp. 177-198), forming as they do "discontinuous reaction series". The zoned hornblende itself may be considered as an example of "continuous reaction".

Apatite is an important accessory mineral, occurring as crystals more than 1 mm. in length, and 0·3 mm. in diameter. A few grains of interstitial orthoclase have been detected, as well as idiomorphic sphene and iron ores.

Chlorite is partly an alteration product of the biotite, and partly interstitial and deuteric. There are a few grains of interstitial calcite, which also appear to be deuteric.

A chemical analysis of the diorite-gabbro appears below (p. 170).

The hornblende-gabbro outcropping at Kelly's Point and through the beach sand, about three-quarters of a mile to the north, appears to be a local modification of the diorite-gabbro, which it resembles in many particulars. It contains all the minerals present in the diorite-gabbro (though in somewhat different proportions) and a few others in addition.

In the handspecimen, it is a black phanerocrystalline gabbroic rock, and is medium-grained. Under the microscope it is seen to have a texture similar to that of the diorite-gabbro, and consists of hornblende, plagioclase, augite, hypersthene, biotite, apatite, sphene, iron pyrites and magnetite or ilmenite, and also epidote and calcite. No olivine has been detected with certainty.

The plagioclase is not so abundant as in the diorite-gabbro, but is more basic in composition, being basic labradorite ($Ab_{35} An_{65}$) and there is a corresponding increase in the proportion of ferromagnesian minerals present, the most important of which is the hornblende.

The augite occurs as grains up to 1·5 mm. in diameter, always surrounded by and changing into brownish hornblende in parallel orientation. It appears to be a normal, colourless monoclinic pyroxene. In addition, there is present a small quantity of a rhombic pyroxene, with straight extinction and marked pleochroism from pink to pale green, which is evidently hypersthene. Like the augite, it may be seen changing to hornblende. Small rounded patches of serpentinous material in the hornblende appear to be the remains of olivine grains. The hornblende is identical with that in the diorite, showing a variation in colour from dark brown or greenish-brown in the centre, to a pale bluish-green at the edges of the larger crystals and in the smaller crystals; the cleavage and twinning are like those of primary hornblende and not like those of fibrous uralite. Similarly zoned hornblende has been recorded from Garabal Hill by Wyllie and Scott (1913, p. 503). Plate xvii, figs. 5 and 6, show sections of the rock described.

Biotite is more plentiful than in the diorite-gabbro, and is of a peculiar reddish-brown colour; it appears to have formed after the hornblende on which it is moulded. Finally there is a mesostasis of faintly pleochroic epidote, having a strong double refraction, and a small amount of interstitial calcite which appears to be primary.

This rock shows then an excellent example of a "discontinuous reaction series", olivine (probably)—monoclinic and rhombic pyroxene—amphibole—mica. In the change from pyroxene to amphibole the excess of iron and lime in the pyroxene has led to the formation of magnetite as a fine dust, and of epidote and calcite as final products of consolidation of the magma.

Rosenbusch has described the production of uralite from pyroxene as being accompanied by all the phenomena which occur in the case under consideration; namely, the parallel growth of the amphibole about the pyroxene, both augite and hypersthene; the separation of fine magnetite dust, and the production of lime-rich minerals, both epidote and calcite.

There can be no doubt, however, that, in this case, the hornblende is primary, in the sense that it commenced to form as a result of the reaction of the liquid part of the magma with the already crystallized pyroxene, and later formed idiomorphic crystals; and it seems equally certain from the mode of occurrence and chemical nature of the epidote and calcite, that these also may be deuteric minerals, which have been released by the reactions during the consolidation of the magma, just as quartz may occur in quartz-dolerites and quartz-monzonites containing olivine.

Chemical analyses of the typical diorite-gabbro and hornblende-gabbro are given in columns I and II below (p. 170).

The analyses are peculiar in showing high percentages of lime and magnesia and fairly high iron oxides, which, however, might be expected from the basic character of the plagioclase, and the high content of ferro-magnesian minerals. The relatively high percentages of titania and phosphoric acid account for the abundance of sphene and apatite in these rocks.

A study of the norms of the two rocks is interesting. The diorite-gabbro contains more than 56%, and the hornblende-gabbro less than 42% of salic minerals; also the norm of the former contains 1% of quartz (which does not appear in the mode), while nearly 4% of olivine appears in the norm of the latter. This would place both rocks near the border line of "saturated" and "under-saturated" rocks of Professor Shand (1927, p. 124). The close relationship between the diorite-gabbro and hornblende-gabbro is further indicated by their positions in adjacent ranges of the same order according to the C.I.P.W. Classification.

	I.	Ia.	II.	IIa.	III.	IIIa.	IV.
SiO_2	50·44	0·841	49·38	0·823	50·04	0·834	48·24
Al_2O_3	17·05	0·167	13·89	0·135	18·68	0·183	17·88
Fe_2O_3	2·43	0·015	1·89	0·012	0·80	0·005	3·16
FeO	5·24	0·073	6·30	0·088	6·91	0·096	5·95
MgO	10·85	0·271	15·82	0·395	7·79	0·195	7·51
CaO	9·80	0·175	10·12	0·180	9·88	0·177	10·99
Na_2O	1·51	0·024	0·54	0·009	2·35	0·038	2·55
K_2O	0·92	0·010	0·69	0·007	0·12	0·001	0·89
H_2O+	0·65	—	0·58	—	1·74	—	—
H_2O-	0·06	—	0·13	—	0·28	—	1·45
TiO_2	1·10	0·014	0·96	0·012	0·80	0·010	0·97
P_2O_5	0·43	0·003	0·30	0·002	0·16	0·001	0·28
MnO	0·11	0·001	0·14	0·002	0·14	0·001	0·13
O. Con. ...	—	—	—	—	0·89	—	—
TOTAL ..	100·59	—	100·74	—	100·58	—	100·00
Sp. Gr.	2·932	—	2·989	—	2·977	—	—

The norms are as follows:

	I.	II.	III.
Quartz	1·58	—	2·10
Orthoclase	5·56	3·89	0·56
Albite	12·58	4·72	21·13
Anorthite	36·97	33·08	40·03
Diopside	7·07	11·92	6·77
Hypersthene	29·68	37·13	27·04
Olivine	—	3·86	—
Magnetite	3·48	2·78	1·16
Ilmenite	2·13	1·82	1·52
Apatite	1·01	0·67	0·34

I. Diorite-Gabbro, Kelly's Point, Por. 215, Par. Congo. 10 mls. S.E. of Moruya. Auvergnose ["III, 5, 4, 4]. Anal. I.A.B.

II. Hornblende-Gabbro, ½ ml. N. of Kelly's Pt. Por. 290, Par. Congo. Kedabekose [III, 5, (4)5, —]. Anal. I.A.B.

III. Diorite (?), Murgatroyd's Tunnel, New England Dist., *Rec. Geol. Surv. N.S.W.*, 1905-9, Vol. 8, p. 216. Anal. J. C. H. Mingaye, Auvergnose [(II)III, 5, 4, 5].

IV. Average of all Gabbros (Osann), quoted from Daly, Igneous Rocks, 1914, p. 27, Column 52.

For comparison, the analysis of a dioritic rock from the New England District is given in column II. It is very similar to the diorite-gabbro, although the magnesia percentage is not quite so high. Although the exact mode of occurrence of the New England rocks is not given in Mr. Andrews' paper, its association with granites, comparable in chemical character with the Moruya granodiorites and other types, including aplites and lamprophyres which have their equivalents on the South Coast, suggests a similar course of magmatic differentiation and possibly a similar structural cause.

The analysis quoted in column IV is that of the average of all gabbros, including olivine-gabbro, given by Osann, and used by Daly (1914, p. 26). The principal distinction lies in the fact that the average gabbro contains more lime than magnesia, whereas the reverse is true in the case of each of the rocks from Moruya.

Nomenclature of the Basic Plutonic Rocks.

The peculiar chemical nature and mineral constitution of the so-called diorite-gabbro demands some comment, and the name requires some justification. In the handspecimen the rock has a typical "dioritic" appearance, being medium-grained and containing nearly equal proportions of light and dark-coloured minerals. Under the microscope it is found that the felspar is labradorite, $Ab_{47}\,An_{53}$, and the chief ferro-magnesian mineral is hornblende.

According to Harker (1908) the rock would be classified as "hornblende diorite". Other petrologists, such as Daly (1909) and Iddings (1909, Vol. I, p. 376) would call it rather "hornblende gabbro" on account of the calcic nature of the plagioclase. Also, as the silica percentage is less than 52, it would be placed in the gabbro family by Hatch (1914, pp. 195, 216).

The high percentages of lime and magnesia certainly indicate an affinity with the gabbros. It has already been seen that similar difficulty would be encountered in classifying it according to Professor Shand's scheme.

On the whole, it is considered that the name "diorite-gabbro" conveys the best idea of its characteristics, and distinguishes it from the allied but more basic hornblende-gabbro.

Segregation Veins and Patches in the Gabbros.

Reference has already been made to the variety of differentiation products occurring as veins and irregular patches through the diorite-gabbro, caused by the activity of magmatic solutions during the later stages of consolidation of the magma.

These segregations are usually more coarsely grained than the enclosing rock, but are not invariably so; as a rule they are lighter in colour than the gabbro, on account of the predominance of felspar over the ferro-magnesian minerals: they are thus of the nature of pegmatites and aplites. Occasionally, however, the dark minerals preponderate and there is developed a kind of lamprophyric rock.

In all cases the actual boundaries of the segregations are irregular and ill-defined. Sometimes veins of felspathic material about 1 mm. in thickness may extend from the segregation for a short distance along joint planes through the diorite-gabbro, but there is every reason for believing that the formation of these segregations took place when the diorite-gabbro was still hot, and not entirely consolidated, and in fact that the segregations represent the final stages of consolidation of the gabbroic magma.

Two varieties of coarse-grained pegmatities are worthy of note: one is characterized by abundance of orthoclase, and the other by plagioclase. The orthoclase-bearing rock occurs in the diorite-gabbro on a small headland about a quarter of a mile south of Kelly's Point. The rock (M 309) is coarse and even-grained, the absolute grainsize being more than 1 cm. It consists of approximately 65% of pink orthoclase, 25% of black, idiomorphic hornblende, and 10% of white oligoclase, of the composition $Ab_{85}\,An_{15}$. A small quantity of iron pyrites is present.

On the southern side of the cliffs half a mile north of Kelly's Point, several veins of coarse felspathic material, somewhat similar to this rock, again occur through the diorite-gabbro. The ferro-magnesian constituent is practically absent, and the vein consists of about 95% of pink orthoclase, and the rest of white glassy plagioclase.

By far the more common type of pegmatite is that consisting chiefly of white plagioclase and black, idiomorphic hornblende, which may reach a length of 4 cm. Some orthoclase is usually present, and also relatively large grains of sphene. The plagioclase is oligoclase, $Ab_{80}\,An_{20}$.

Another interesting type of segregation is that developed on the southern part of Kelly's Point, which has the appearance of a hornblende-lamprophyre. It occurs in irregular patches, and consists of black hornblende in stumpy crystals about 5 mm. in thickness, and comprising about 40% of the rock, set in a dark greenish groundmass of finely crystalline material. Under the microscope the hornblende shows characters similar to that in the gabbros, being colour-zoned, and containing remnants of augite. The groundmass consists of andesine and colourless augite in almost equal proportions, with some green hornblende, sphene, apatite and interstitial epidote.

Inclusions in the Granodiorite.

There are numerous dark inclusions and "basic segregations" in some parts of the granodiorite and tonalite, particularly along the eastern and southern portions of their outcrops. Narrow veins of the granodiorite frequently intrude the inclusions, and aplite veins traverse host and inclusion alike.

These inclusions may be divided into two classes, (*a*) rocks of sedimentary origin, and (*b*) igneous rocks.

(*a*). The first class contains almost exclusively fragments of quartz-schists, which vary in size from a few inches to several feet in diameter. These inclusions are generally angular, and retain distinct evidence of original bedding similar to that of the intruded quartz-schists of the district. The schist appears to have sharp boundaries against the granodiorite. Under the microscope it is seen to be entirely crystalline, and to consist of quartz, a greenish-brown mica and some plagioclase.

Inclusions of this class are undoubtedly fragments of country rock included in the intrusive igneous mass, and are thus "accidental xenoliths".

(*b*). The rocks included in the second class call for closer consideration. At Moruya these inclusions are far more abundant than those belonging to the first class. There is no doubt that they are not true segregations or secretions which have crystallized in the position in which they are now found, although it is possible that they may have exerted some such influence upon the crystallization of the adjacent rock as that postulated by Bowen (1922, p. 539).

This type of inclusion is usually spheroidal, and consists of a rock which is more finely grained than the normal granodiorite or tonalite. It is really a quartz-mica-diorite. Frequently phenocrysts of plagioclase and poikilitic flakes of biotite are present (Plate xvii, fig. 4). A typical specimen consists of plagioclase, biotite, green hornblende, interstitial quartz, and a small amount of interstitial orthoclase, iron ore, acicular crystals of apatite, with occasional sphene, zircon and iron pyrites. The peculiar habit of the ragged flakes of biotite enclosing crystals of other minerals, notably felspars, in a poikilitic manner, is quite characteristic, and resembles the structure of some normal mica-diorites.

The following is the chemical composition of a typical specimen of this class of inclusion.

SiO_2	58·58	0·976
Al_2O_3	18·33	0·179
Fe_2O_3	1·96	0·012
FeO	5·01	0·069
MgO	3·69	0·092
CaO	6·14	0·110
Na_2O	1·99	0·032
K_2O	1·28	0·014
H_2O + ...	1·44	—
H_2O −	0·09	—
TiO_2	1·06	0·014
P_2O_5	0·30	0·002
MnO	0·19	0·003
TOTAL ..	100·06	
Sp. Gr.	2·808	

Norm.	
Quartz	21·36
Orthoclase	7·78
Albite	16·77
Anorthite	28·63
Corundum	3·06
Hypersthene	15·27
Magnetite	2·78
Ilmenite	2·13
Apatite	0·67

Basic Inclusion in Granodiorite, Quarry near Moruya, M.L.4, Par. Tomaga. Bandose [II, 4, "4, 4]. Anal. I.A.B.

A comparison of this analysis with that of the granodiorite shows that there is the same order of difference in the chemical characters of the inclusion and host as that which has been observed by Harker and Marr (1891, p. 279), Phillips (1880, p. 1), and others.

With a relative decrease in the amount of silica and alkalis in the inclusion, there is a corresponding increase in the amounts of iron, lime and magnesia.

On reference to the variation-diagram for the plutonic complex, given on page 183, it will be seen that the composition of a hypothetical member of the complex containing 58½ per cent. of silica, is remarkably close to that of the included quartz-mica-diorite. It therefore seems quite probable that the host and inclusion are co-magmatic, and that the quartz-mica-diorite represents an early-formed member of the igneous series, which was shattered and included in the granodiorite during its injection into its present position.

These "basic segregations" are therefore really "cognate xenoliths".

(iv). *Field Occurrence and Petrography of the Dykes.*

Associated with the Moruya plutonic complex and the related sediments are several systems of dykes, some of which are clearly hypabyssal equivalents of the plutonic series, and others whose relationships are more obscure. Individual dykes vary in width from one or two feet to about twelve or fourteen feet, but the majority average a thickness of about four feet, and they are generally vertical.

In some areas they are very numerous, although individual dykes cannot usually be traced for any great distance, on account of surface weathering.

The directions of strike of the dykes seem to bear a definite relation to the lithological character of the dyke, and are probably dependent on the directions of crustal strain and stresses acting prior to and during the time of their injection. For this reason it will be convenient to consider them in the following order, which is probably the order of their intrusion.

(1) Muscovite-granite apophysis.
(2) Granite-aplites and pegmatites, including graphic pegmatite.
(3) Hornblende-quartz-porphyrite and granite-porphyry.
(4) Mica-lamprophyre.
(5) A variety of intermediate and basic types.

(1) A dyke of muscovite-biotite-granite occurs in the Moruya Council's metal quarry at Yarragee, about a mile west of Moruya, where it intrudes vertically bedded and banded quartz-schists, along their direction of strike, which is almost north and south. It is about four feet in width and consists of granite very similar to the border phases of the biotite-granite in the main batholith.

In thin section the rock shows a rather coarsely crystalline texture, and the grainsize is variable; it is granitoid and shows evidence of considerable strain. It consists of quartz as irregular interlocking grains, acid plagioclase (oligoclase), orthoclase and microperthite similar to that in the biotite-granite, with abundant muscovite in parallel intergrowth with biotite. The biotite contains numerous tiny, dark brown haloes, in the centre of which a crystal of zircon may occasionally be detected. A small amount of iron ore is present. It is noteworthy that muscovite does not occur in the biotite-granite normally, except in some of the border phases and apophyses.

(2) The granite-aplites and pegmatites show some variation in composition and texture; they usually intrude the granodiorite and tonalite, but they also occur in the diorite-gabbro.

There is greater variation in the direction of strike and the amount of dip in the case of the aplites than in any of the other dyke-rocks. In the quarry on the north side of the Moruya River, narrow veins of aplite, less than one inch in thickness, traverse the granodiorite, dipping in a direction N. 45° E. at about 45°, which is parallel to the direction of strike of the principal joint system in the granodiorite. Veins of this type may be seen in the granite columns of the G.P.O., Sydney. In the quarry on the southern side of the River (Louttit's), there are four or five veins of aplite about one inch in thickness, and from three to eight feet apart, as well as a dyke two feet in thickness, which dip S. 40° W. at 50°.

These veins always cut through the slaty and other inclusions in the granodiorite.

There is a series of eight or nine fine-grained aplitic dykes on the shore of Lake Coila about a mile north of the Bar. They average about two feet in width, and are only a few yards apart, running in a direction W. 20° N. Half a mile to the north are numbers of smaller aplite veins. Several aplite dykes intrude the tonalite of the Tuross peninsula, between Lakes Coila and Tuross, running in a direction N. 60° E. and others occur between Lake Coila and the sea. One dyke in portion 294, Parish of Congo, appears to have been faulted at right angles, resulting in the concentration of ground water at the intersection of dyke and fault, with the formation of a small spring or permanent soakage.

South of Kelly's Point there are two well-defined dykes which dip to the north at 60°, and form prominent outcrops through the beach-sand; one has weathered to a yellow colour and the other is red.

The widest aplite dyke is that at Kelly's Point, indicated on the sketch-map on page 153. It is about twelve feet thick and dips to the north-east at 40°, but is not constant in direction as it swings round to the north. It has intruded the tonalite, which in turn has intruded the diorite-gabbro, but is intruded by the later basaltic dykes. Unweathered specimens of this dyke were chosen for analysis as being representative of the aplites.

The microscope shows it to be a fine-grained and aplitic rock, consisting of quartz, acid plagioclase and some biotite, with abundant interstitial orthoclase, which has been the last mineral to crystallize out. No muscovite has been observed in this particular rock, although some of the other aplites contain small amounts of both biotite and muscovite, while in others there is a complete absence of any minerals other than quartz, orthoclase and acid plagioclase.

The chemical analysis of this aplite is quoted below.

	I.	Ia.	II.	IIa.
SiO_2	77·92	1·299	74·00	1·233
Al_2O_3	11·99	0·118	14·49	0·142
Fe_2O_3	0·21	0·001	1·10	0·007
FeO	0·74	0·010	0·45	0·006
MgO	0·24	0·006	0·44	0·011
CaO	1·23	0·021	0·92	0·016
Na_2O	2·29	0·037	3·29	0·053
K_2O	4·78	0·051	4·85	0·051
H_2O+	0·26	—	0·56	—
H_2O-	0·14	—	0·18	—
CO_2	abs.	—	abs.	—
TiO_2	0·18	0·003	0·14	0·002
P_2O_5	0·03	—	0·05	—
MnO	trace	—	0·08	0·001
BaO	—	—	0·06	0·001
TOTAL	100·01	—	100·61	—
Sp. Gr.	2·646	—	2·630	—

Norms.	I.	II.
Quartz	43·02	33·84
Orthoclase	28·36	28·36
Albite	19·39	27·77
Anorthite	5·84	4·73
Corundum	0·92	2·14
Hypersthene	1·39	1·10
Magnetite	0·23	1·16
Ilmenite	0·46	0·30
Haematite	—	0·32

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I. Aplite, Kelly's Point, 10 mls. S.E. of Moruya. Anal. I.A.B. Tehamose [I, 3, 2, ″3].

II. Aplitic Granite, 2 mls. E. of Tenterfield. Anal. J. C. H. Mingaye. *Rec. Geol. Surv. N.S.W.*, viii, Pt. 3, 1905-9, p. 225. Tehamose [I, 3(4), (1)2, 3]. Norm recalculated.

The rock is a normal aplite. The analysis of an aplitic granite belonging to the euritic period in the history of the New England Tableland intrusions is quoted in Column II to show the close resemblance to the Moruya rock. Some of the acid granites from Bolivia are also very similar.

It will be shown later that the rock bears a close magmatic relation to the plutonic types comprising the batholith, and was probably injected shortly after their consolidation.

A beautiful example of graphic pegmatite occurs as a dyke on the south-western shore of Lake Coila, in portion 39, Parish of Congo. It consists of crystals of yellowish-pink orthoclase, averaging two inches in diameter, and white acid plagioclase, both graphically intergrown with quartz. Flakes of biotite about half an inch in diameter are associated with the plagioclase. Under the microscope the orthoclase shows also a fine perthitic intergrowth with plagioclase.

(3) Dykes of the third class, the hornblende-quartz-porphyrites, have a very wide distribution, occurring throughout the whole of the mapped area, and intruding all phases of the igneous complex, as well as the adjacent slate series. It was found quite impracticable to indicate all of these dykes on the map, as several hundred must occur in the district.

The greater number run in a direction slightly north of east, although a few run approximately E. 30° N. and some strike E. 30° S. As a result of weathering, the positions of the dykes (which frequently occur in groups) may be indicated by a series of parallel trenches, or by a series of parallel rock-ridges, depending on the relative resistance to weathering of the intruded and intrusive rock. The dykes are rarely more than a few feet in width.

The consistent and characteristic alteration of the rock itself, suggests that such is due not merely to surface weathering, but to magmatic processes which have accompanied or closely followed the dyke formation. It is difficult to obtain a specimen which looks really fresh. The freshest specimens are dark grey in colour, but on weathering the rock becomes light greenish-grey.

Often the rock is very fine-grained, so that only crystals of hornblende can be distinguished from the lithoidal groundmass. Coarser varieties show elongated phenocrysts of hornblende or hornblende and plagioclase, never exceeding a few millimetres in length, set in a phanerocrystalline groundmass.

Under the microscope, these rocks are seen to be holocrystalline, slightly porphyritic in plagioclase and hornblende or its pseudomorphs. The phenocrysts are set in a fine-grained or even microcrystalline groundmass, consisting chiefly of plagioclase and quartz and the remains of hornblende grains, with a small amount of biotite and muscovite. The fineness of grain of the groundmass makes it difficult to recognize the variety of plagioclase, or the presence of orthoclase with any degree of certainty.

The hornblende phenocrysts are idiomorphic, and very seldom fresh. Such as are fresh have a greenish-brown colour approaching that of basaltic hornblende. A characteristic feature is the alteration to grains of clear carbonate material, including calcite, and colourless or pale green epidote, with associated iron ore. Green chloritic material showing prussian-blue interference colours occurs in some cases. The plagioclase phenocrysts are andesine, Ab_{65} An_{35}.

The groundmass consists of an intimate association of felspar, chiefly plagioclase, and quartz. In some cases the felspars occur as stout little prisms with quartz filling the interstices, in other cases (M 123, M 206) there is a micrographic intergrowth of the quartz and felspar, producing a kind of granophyric structure.

Occasionally the structure is micropoikilitic, quartz grains forming a matrix for smaller, optically independent grains of felspars.

Alteration products such as epidote, chlorite, calcite and iron ore are scattered through the groundmass, and a pale yellow variety of sphene and some apatite crystals are present in some sections.

It will be seen that the rock (Plate xviii, fig. 3) is a peculiar type. As a field name "lamprophyre" seems appropriate, and the alteration of hornblende to carbonates and epidote is certainly characteristic; but there is an unusually high percentage of quartz present in the groundmass, which probably indicates peculiar conditions of crystallization.

A specimen from a dyke cutting across the main road about half a mile north of Bergalia Store and Post Office, was selected for chemical analysis, as being relatively fresh and representative of the series. The result is given in Column I below.

	I.	Ia.	II.	IIa.
SiO_2	66·11	1·102	69·33	1·155
Al_2O_3	17·26	0·169	15·23	0·149
Fe_2O_3	0·63	0·004	0·97	0·006
FeO	2·68	0·037	2·56	0·035
MgO	1·41	0·035	1·01	0·025
CaO	4·72	0·084	3·74	0·067
Na_2O	2·11	0·034	2·73	0·044
K_2O	1·02	0·011	1·42	0·015
H_2O+	1·72	—	1·56	—
H_2O-	0·10	—	0·18	—
CO_2	1·22	0·027	abs.	—
TiO_2	0·49	0·006	0·94	0·012
P_2O_5	0·13	0·001	0·06	0·001
MnO	0·12	0·001	0·11	0·001
TOTAL	99·72	—	99·84	—
Sp. Gr.	2·719	—	2·711	—

Norms.	I.	II.
Quartz	39·66	37·80
Orthoclase	6·12	8·34
Albite	17·82	23·06
Anorthite	15·01	17·79
Corundum	7·14	2·65
Hypersthene	7·20	4·88
Magnetite	0·93	1·39
Ilmenite	0·91	1·82
Apatite	0·34	0·34

I. Hornblende-quartz-porphyrite. Dyke, ½ ml. N. of Bergalia. Anal. I.A.B. Susquehannose [I(II), 3, 3, 4].

II. Granite-porphyry. Condoin Creek, Por. 33, Par. Bergalia, Anal. I.A.B. Susquehannose [I, 3″, 3, 4].

The chemical composition thus shows a remarkable similarity to that of the typical granodiorite from Dorman, Long and Company's quarry, the main difference being that the percentage of alkalis is lower (by two per cent.) in the dyke rock. This is reflected by a decrease in the amount of felspar with a corresponding increase in the amount of quartz in the norm. As a result the rocks are placed in corresponding subrangs of adjacent orders according to the C.I.P.W. classification.

Somewhat similar rocks are described by Iddings (1891, p. 588) from Electric Peak in the Yellowstone Park, and called by him "porphyrites" of various kinds. The chemical analyses of these rocks show a similar percentage of silica but the alkalis exhibit a slightly higher percentage than in the Moruya rock.

Similar dyke-rocks of Palaeozoic age in the Cape Colville Peninsula in the North Island of New Zealand have been described by Professor Sollas (1905, p. 119) as porphyrites, but unfortunately no chemical analyses are available. The frequent alteration of hornblende to epidote is specially noticed in these rocks.

The nomenclature of the Moruya dyke-rocks has been the subject of serious consideration, and it seems that the name "hornblende-porphyrite" or "hornblende-quartz-porphyrite" would be most appropriate for these peculiar types.

The analysis given in Column II is that of a granite-porphyry intruding the biotite-granite at Condoin Creek, south-west of Moruya, in portion 33, Parish of Bergalia. Its composition is close to that of the hornblende-quartz-porphyrite.

The mode of occurrence is somewhat obscure, as the outcrops are poor. As far as can be ascertained it occurs as a dyke or small stock near the border of the granite.

In the handspecimen, phenocrysts of plagioclase, quartz and biotite are set in a lithoidal groundmass.

Under the microscope, the plagioclase is seen to be oligoclase of the composition $Ab_{75} An_{25}$, and the groundmass is holocrystalline and consists of felspar, quartz, biotite, green hornblende, iron ore and a little orthoclase and apatite.

(4) Mica-lamprophyre outcrops on the shore of Lake Coila in portion 295, Parish of Congo, as a vertical dyke, two feet in width, running in a direction W. 20° N., parallel to the series of associated dykes of aplite, hornblende-porphyrite and more basic types, which are intruding the diorite-gabbro in this locality.

The rock shows the characteristic weathering of a lamprophyre, the colour of the fresh rock being light greenish-grey, which changes to a reddish-brown shade on weathering.

Idiomorphic biotite is the only mineral visible in the handspecimen. It is very abundant and gives a kind of schistose appearance to the rock.

Under the microscope a few grains of altered plagioclase may be seen in addition to biotite, which contains abundant grains of iron ore. The groundmass is microcrystalline and probably felspathic (Plate xviii, fig. 4).

Its chemical composition has not been determined, so that its genetic relationship with the igneous complex cannot be proved. The occurrence of similar lamprophyres is rather characteristic of the closing phases of igneous activity in many parts of the world. The susceptibility of this type of rock to rapid weathering probably accounts for the fact that no other dykes of a similar character have been observed in the district.

(5) Rocks of a basaltic appearance occur as vertical, or steeply inclined dykes intruding all phases of the igneous complex, and also the altered sedimentary series. The width of the dykes varies from two and a half to twelve feet, the

majority being about four feet wide; the direction of strike varies from N. 50° E. to E. 10° S. The general trend is about E. 10° N.

The majority of these dyke-rocks are finely grained and dark-coloured, not markedly porphyritic, although there are a few rather striking exceptions. In the handspecimen they may be readily distinguished from the Tertiary basalts, occurring as interbedded flows or sills in the later sediments.

Petrographically, there seems to be a fair amount of variation in these basaltic-looking rocks. Some specimens show resemblances to the rocks previously described as hornblende-quartz-porphyrites. The rocks are always holocrystalline, and usually slightly porphyritic. The phenocrysts consist of plagioclase or hornblende in some cases, or in a few cases they are of colourless augite and pseudomorphs after olivine. The groundmass is generally medium-grained, and consists of plagioclase and green hornblende, with a small amount of quartz and accessory minerals, apatite and iron ore.

Associated with these basaltic rocks are a few unusual types which deserve special mention, but which are reserved for detailed description in a later communication. These outcrop at Kelly's Point and on the shore of Lake Coila. They contain xenoliths of basic plutonic rocks, and xenocrysts of plagioclase, biotite, brown hornblende, augite and dark red garnet.

It is considered that the dykes belonging to the first three groups certainly belong to the later stages of the Palaeozoic igneous activity in this area, and are magmatically related to the plutonic series; there is insufficient evidence for assigning an age to the mica-lamprophyre; while some of the basaltic types containing green hornblende are probably related to the granodiorites, others, particularly those containing large xenocrysts, may be of much later origin.

(v). *Petrogenesis of the Palaeozoic Igneous Rocks.*

(*a*) *Genetic Relationships.*

The field relations and associations of the Palaeozoic igneous rocks naturally lead to the consideration of their magmatic relationships. There is a wide range of rock types from acid to basic, and from plutonic to hypabyssal or volcanic types. The field evidence suggests some magmatic relationships, in that the main intrusion takes the form of a complex batholith in which the later injections of magma have been progressively more acid than the earlier ones. Acid aplite dykes probably represent the later phases of consolidation of the injected magma. Subsequent strains and stresses have caused the development of joints and other planes of weakness, along which dykes of hornblende-quartz-porphyrite and then basaltic and lamprophyric rocks have been injected.

The general sequence therefore, is such as might be expected in a complete igneous complex.

The mineralogical composition confirms this supposition. For the sake of clearness and simplicity a table is given below showing the mineralogical composition of all the rocks which have been chemically analysed, which comprise most of the principal types described. The rocks are arranged in order of decreasing basicity. It will be seen that the order of crystallization of the minerals present shows a similar order of decreasing basicity.

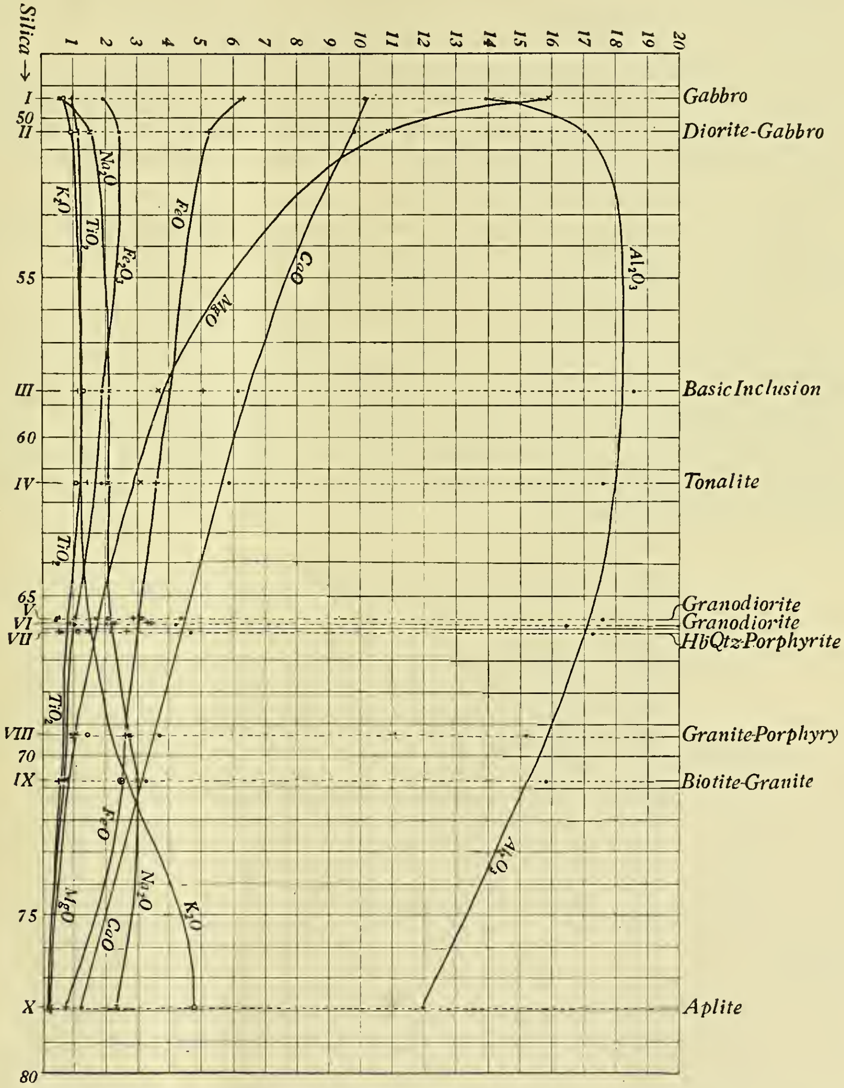
The ferromagnesian minerals, with the exception of biotite, are more abundant in the basic members of the system; some biotite is present throughout the whole series, with a notable increase in amount towards the acid end. The plagioclases by themselves form a definite index of the composition of the rock; the oldest rocks, the gabbro and gabbro-diorite, are characterized by labradorite of fairly constant composition, the tonalite and granodiorite show a variation from andesine to oligoclase-andesine, while the later biotite-granite contains oligoclase of a constant composition. Orthoclase is important only in the biotite-granite and aplite, although smaller quantities do occur in the more basic types. Quartz is present in all but the basic types, increasing in abundance in the acid members.

	I. Hornblende-Gabbro.	II. Diorite-Gabbro.	III. Basic Inclusion.	IV. Tonalite.	V. Granodiorite.	VI. Granodiorite.	VII. Hb.-qtz.-Porphyrite.	VIII. Granite-Porphyry.	IX. Biotite-Granite.	X. Aplite.
Iron Ore	+	+	+	+	+	+	+	+	+	—
Olivine	?	—	—	—	—	—	—	—	—	—
Hypersthene	+	—	—	—	—	—	—	—	—	—
Augite	+	+	—	—	—	—	—	—	—	—
Brown Hornblende ..	+	+	—	—	—	—	?	—	—	—
Green Hornblende ..	+	+	+	+	+	+	?	+	—	—
Biotite	+	+	+	+	+	+	+	+	+	+
Muscovite	—	—	—	—	—	—	+	—	—	?
Labradorite	+	+	—	—	—	—	—	—	—	—
Andesine	—	—	?	+	+	+	+	—	—	—
Oligoclase	—	—	—	—	—	—	—	+	+	+
Orthoclase	—	+	+	+	+	+	?	+	+	+
Quartz	—	—	+	+	+	+	+	+	+	+
Sphene	+	+	+	+	+	+	+	—	—	—
Apatite	+	+	+	+	+	+	?	+	+	?
Zircon	—	—	+	+	+	+	—	?	+	—
Epidote	+	—	—	—	—	—	+	—	—	—
Calcite	+	—	—	—	—	—	+	—	—	—

Of the accessory minerals, iron ore and apatite occur in small quantities throughout; sphene is in greater abundance than is usual, especially toward the basic end of the series, and zircon is relatively important in the granodiorite and biotite-granite.

Epidote and calcite occur in unweathered specimens of the gabbro and the hornblende-quartz-porphyrite alone, where they are undoubtedly minerals of late-magmatic or deuteric crystallization.

The chemical evidence is probably the most convincing in proving the consanguinity of the rocks under consideration. A table of the chemical analyses of



Text-fig. 4.—Variation diagram for the igneous complex of the Moruya district.

all the rocks from this district, which have been analysed by the writer, is given below in the same order as in the mineralogical table, thus including the chief plutonic types, some of the important dyke rocks, and a cognate xenolith from the granodiorite.

It will be seen that on the whole there is a gradation throughout the series for each of the constituent oxides. This has effected a corresponding variation in the values of the specific gravities, which are quoted below the analyses.

A table of the calculated norms further bears out the consanguinity of the various members of the series, which is emphasized in the table of their classifications by the regular gradation in class, order, rang and subrang alike.

The ten chemical analyses have been plotted to form a variation-diagram (Text-fig. iv) of the type used by Harker (1909, p. 129), where the silica percentages are used as abscissae, giving a range of nearly 30 per cent., and the percentages of the other oxides are plotted as ordinates. Smoothed curves have been drawn through the mean positions of these points.

The curves thus obtained give the best picture of the series as a whole, showing without doubt the genetic relationships of the series, which forms a true plutonic complex, including basic, intermediate and very acid types.

A consideration of the form of each of the curves representing the various oxides shows that the series is a typical subalkaline or calcic assemblage, characterized by the flat convex curve for alumina, concave declining curve for magnesia, and declining curves, almost straight lines, for lime and iron oxides; the curves for the alkalis, particularly potash, show a rise from the basic to the acid end of the series. Another feature shown by the analyses is the relative importance of titania: in the basic gabbro the amount of titania is greater than that of either soda or potash.

	1.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2	49·38	50·44	58·58	61·44	65·72	65·83	66·11	69·33	70·78	77·92
Al_2O_3	13·89	17·05	18·33	17·61	17·63	16·44	17·26	15·23	15·77	11·99
Fe_2O_3	1·89	2·43	1·96	1·86	0·42	1·03	0·63	0·97	0·69	0·21
FeO	6·30	5·24	5·01	3·59	2·80	3·33	2·68	2·56	2·44	0·74
MgO	15·82	10·85	3·69	3·09	1·73	2·00	1·41	1·01	0·72	0·24
CaO	10·12	9·80	6·14	5·88	4·36	4·24	4·72	3·74	2·53	1·23
Na_2O	0·54	1·51	1·99	2·03	3·14	2·25	2·11	2·73	2·88	2·29
K_2O	0·69	0·92	1·28	1·03	2·12	3·40	1·02	1·42	2·44	4·78
H_2O + ...	0·58	0·65	1·44	1·17	1·03	0·67	1·72	1·56	0·50	0·26
H_2O −	0·13	0·06	0·09	0·10	0·06	0·10	0·10	0·18	0·06	0·14
TiO_2	0·96	1·10	1·06	1·42	0·41	0·78	0·49	0·94	0·45	0·18
P_2O_5	0·30	0·43	0·30	0·33	0·19	0·21	0·13	0·06	0·25	0·03
MnO	0·14	0·11	0·19	0·09	0·08	0·08	0·12	0·11	0·08	Tr.
Other constituents .	—	—	—	—	0·32	—	1·22	—	—	—
TOTAL ..	100·74	100·59	100·06	99·64	100·01	100·36	99·72	99·84	99·59	100·01
Sp. Gr.	2·989	2·932	2·808	2·768	2·729	2·741	2·719	2·711	2·688	2·646

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Quartz	—	1·38	21·36	27·72	25·92	26·22	39·66	37·80	36·84	43·02
Orthoclase .	3·89	5·56	7·78	6·67	12·23	20·02	6·12	8·34	14·46	28·36
Albite	4·72	12·58	16·77	16·77	26·72	18·86	17·82	23·06	24·63	19·39
Anorthite ..	33·08	36·97	28·63	27·24	20·85	20·29	15·01	17·79	11·68	5·84
Corundum .	—	—	3·06	3·16	2·55	1·63	7·14	2·65	4·08	0·92
Zircon	—	—	—	—	0·37	—	—	—	—	—
Diopside ..	11·92	7·07	—	—	—	—	—	—	—	—
Hypersthene	37·13	29·68	15·27	10·60	8·26	9·22	7·20	4·88	5·23	1·39
Olivine	3·86	—	—	—	—	—	—	—	—	—
Magnetite .	2·78	3·48	2·78	2·55	0·70	1·39	0·93	1·39	0·93	0·23
Ilmenite ...	1·82	2·13	2·13	2·74	0·76	1·37	0·91	1·82	0·76	0·46
Pyrite	—	—	—	—	0·24	—	—	—	—	—
Apatite	0·67	1·01	0·67	0·67	0·34	0·34	0·34	0·34	0·34	—
Class	III	″III	II	′II	I(II)	I(II)	I(II)	I	I	I
Order	5	5	4	(3)4	4	4	3	3″	3′	3
Rang	(4)5	4	″4	″4	3	3	3	3	2(3)	2
Subrang ...	—	4	4	4	4	3	4	4	(3)4	″3
Magmatic Name.	Kedabekase.	Auvergnose.	Bandose.	Bandose (nr. Yellowstonose).	Yellowstonose.	Amiatose (nr. Yellowstonose).	Susquehannose (nr. Yellowstonose).	Susquehannose (nr. Yellowstonose).	Alsbachose (nr. Tehamose).	Tehamose.

I. Gabbro (M.109). Kelly's Point, south-east of Moruya.
II. Diorite-gabbro (M.278). Kelly's Point.
III. Inclusion in Granodiorite (M.121). Quarry, 2 mls. E. of Moruya.
IV. Tonalite (Quartz-Diorite). (M.175). Kelly's Point.
V. Granodiorite (M.122). Quarry, 2 mls. E. of Moruya.
VI. Granodiorite (M.127). 1 mile south-west of Moruya.
VII. Hornblende-quartz-Porphyrite (M.123). Dyke, near Bergalia.
VIII. Granite-porphyry (M.233). Condoin Creek, south-west of Moruya.
IX. Biotite-Granite (M.343). 3 mls. north-west of Moruya.
X. Aplite (M.105). Dyke, Kelly's Point, 10 mls. south-east of Moruya.

There is a marked similarity between the series at Moruya and the classic series at Garabal Hill, which was described by Dakyns and Teall (1892, pp. 104-121) and later by Wyllie and Scott (1913).

In the case of Garabal Hill the silica percentages range from 38·6 to 75·8, and thus differ slightly from those at Moruya. Within the latter limits the modified variation-diagram for the Garabal Hill series, as given by Harker (1909, p. 129), bears a striking resemblance to that of the Moruya series. The only real difference is the relatively sudden change in the amount of curvature of the oxide-curves between the diorite-gabbro and the more basic gabbro at Moruya, which is suggestive of complementary, as opposed to serial differentiation. This idea is supported by the nature of the field occurrence of the hornblende-gabbro. Nevertheless the senses or directions of curvature in the basic ends of both the Garabal Hill and the Moruya series are similar.

(*b*). *Shape and Nature of the Intrusion.*

The intrusive nature of the igneous mass may be seen at its junction with quartz-schists, about half a mile east of Dorman, Long and Co.'s main quarry, M.L.4, Parish of Tomaga, where a chilled marginal phase of aplitic granite is developed for a short distance from the contact.

A somewhat similar aplitic granite is developed at the contact with slates near the 5-mile peg from Moruya towards Sydney. Also at Yarragee a couple of miles west of Moruya, a granitic dyke, closely related to the granodiorite mass, has intruded quartz-schists in the Council's metal quarries. About a mile and a half south-west of the town of Moruya there are several small patches of folded sedimentary rocks, which appear to have been rifted off the roof of the magma-chamber, as the fold-axes are not parallel to those uniformly developed in the adjacent sediments. No assimilation of these sediments has been observed in the granodiorite.

East of Moruya, there are other examples of included sediments, the largest of which was probably not detached, but formed a "roof-pendant" as defined by Daly (1914, p. 100). It occurs in portions 121 and 122, Parish of Moruya, and consists of meridionally folded, banded quartzites and slates, with interbedded tuffaceous and other volcanic material. The junction with granodiorite is sharply defined in many places, and there appears to be no trace of assimilation.

Elsewhere, the actual junction between the igneous rock and the altered sediments is obscured by weathering products, but the mass cuts across the bedding planes of the associated slates and schists, apparently without affecting their direction of strike.

Numerous small inclusions of country rock in the granodiorite, and the slight, though marked, parallel banding it exhibits parallel to the main trend of its outcrop, and the well-marked zone of contact metamorphism are considered to be further evidences of its intrusive nature.

No vertical cross-sections of the intrusion are available, but from a study of the detailed map of the district, and the foregoing description, it is obvious that the intrusion is portion of a batholith, which is elongated in a north-north-westerly direction and which has cut across the planes of bedding and schistosity of the country rock. These features are shown by Daly (1914, p. 95) to be characteristic of batholiths, although there may be some doubt as to whether the longer axis of the batholith is, in this case, "parallel to the tectonic axis of the mountain-built zone in which the mass is situated". It is at least interesting to note that the main trend of the Moruya River from Merricumbene to Larry's Crossing, where the river has entrenched itself to a depth of several hundreds of feet in the slate series, is in a direction approximately parallel to the elongation of the batholith, evidently following a line of weakness in this direction, possibly along a Palaeozoic fault-zone. The deflection of the river course to a southerly direction for four miles below Larry's Crossing is due to the outcrop of a hard bar of quartz-felspar-porphyry, as shown on the general map of the district.

Dr. H. I. Jensen (1908, p. 306) has noted faulting, through Devonian rocks in the Ettrema gorges near Sassafras, where Rolfe's "creek follows . . . . an old fault running N.N.W. to S.S.E. and antedating the deposition of Permo-Carboniferous strata".

This area lies to the north of Moruya, where the slates are overlain by Permo-Carboniferous strata, except where they are exposed by stream erosion.

(c). *History of the Intrusion.*

Summarizing the events which have taken place in the igneous history, it is evident that there was first an intrusion of basic rocks, hornblende-gabbro and diorite-gabbro, along a zone of weakness in a north-north-westerly direction through folded early Palaeozoic sediments. This intrusion was followed by an injection of tonalite and granodiorite, and later by biotite-granite, each of which has its own peculiar and characteristic composition, yet shows indubitable evidence of consanguinity with the other types, the whole series occurring as a plutonic complex in the form of a composite batholith.

The cooling and contraction of the plutonic rocks allowed the formation of veins and dykes of aplite from the residual magma, and at a later period, dykes of intermediate and more basic composition, the hornblende-quartz-porphyrites and basaltic types, were injected along fissures generally parallel to the system of joints, which are transverse to the batholithic axis.

The metalliferous deposits in the neighbourhood of Condoin Creek, south-west of Moruya, probably represent the closing phase of this igneous activity.

Thus all the evidence available, the field relations and the mineralogical and chemical evidence, points to the fact that magmatic differentiation of a serial nature has been effected by some means in the original magma-reservoir.

It seems that the differentiation has not taken place in the position in which the rocks now occur, for there are definite intrusive relations between the gabbro and the tonalite, and there is not a gradual transition in the composition of the three main plutonic types, gabbro, tonalite-granodiorite, and biotite-granite.

With the exception of dyke rocks, the "basic segregations" are the only rocks which are intermediate in composition between these main types, and it has been shown that they are really cognate xenoliths. Further, the disposition of the outcrops of the chief rock-types does not indicate differentiation in place. If separation into basic and acid fractions of the magma had occurred, it might be expected that the basic portion would occupy the lower part of the magma-chamber, yet actually the gabbros occur at higher altitudes than the more acid types, although there is no evidence in the surrounding invaded sediments that any tilting movement has taken place in the district.

The occurrence of granite at Conjola, seventy miles north and also near Bodalla, fifteen miles south of Moruya, apparently identical with the biotite-granite north-west of Moruya, suggests a common source of origin in an inter-crustal reservoir. It is considered that the batholith at Moruya is but one expression of Palaeozoic igneous activity in the South Coast district, and that the complete history will not be known until the other granitic and monzonitic intrusions of the South Coast have been studied.

Attention has already been called to the similarity of the chemical nature of the series at Moruya and at Garabal Hill, and closer investigation reveals other resemblances. The series at Garabal Hill was used by Harker (1909) as an example of a typical subalkaline plutonic complex, and later Bowen (1922, p. 189) used it to illustrate the reaction principle in petrogenesis.

At Moruya, as well as at Garabal Hill, the order of intrusion is that of decreasing basicity and increasing alkalinity, which is considered by Brögger (1895) to be the normal order of intrusion. Also, there are parallel orders of appearance and disappearance of the constituent minerals in both series, which, according to Bowen, "is the very essence of the reaction series" as opposed to eutectic crystallization. Nevertheless, both series are really discontinuous in that they contain two gaps, one between the basic and intermediate types and one between the intermediate and acid plutonic rocks, thus presenting certain difficulties in the explanation of the differentiation. These difficulties led Wyllie and Scott to postulate a separate origin of the ultrabasic and acid magmas at Garabal Hill.

At Moruya, the obvious genetic relationships of the exposed rocks do not seem to be in accordance with this idea, and the most probable explanation of the rock association appears to be that differentiation of an originally homogeneous magma took place in an intercrustal reservoir by means of fractional crystallization and the sinking of crystals, similar to that postulated by Bowen (1915-1919). Orogenic earth movements took place when the liquid portion of the magma had reached about the composition of the diorite-gabbro, and portion of this magma was injected along the zone of weakness in the upper layers of the earth's crust, now occupied by the Moruya batholith. This portion of the magma crystallized as the diorite-gabbro.

Meanwhile, crystallization-differentiation of the remaining liquid was proceeding quietly in the main magma chamber, the liquid becoming progressively more acid as the minerals of early crystallization were formed. Further earth movements caused relief of pressure and allowed of the injection of a portion of the remaining liquid magma, possessing at this time a composition about that of the tonalite and granodiorite. As a relatively large portion of this was injected, it is possible that some local differentiation took place during its consolidation, or the injected magma may have been already partly differentiated, thus producing the variation from tonalite to granodiorite.

Further differentiation of the magma in the main reservoir produced a liquid still more acid than the granodiorite, and later movement allowed of its intrusion into the position now occupied by the biotite-granite.

It seems feasible that the masses of hornblende-gabbro and the quartz-mica-diorite xenoliths, both of which are more basic than their hosts, the diorite-gabbro and granodiorite respectively, were fragments of more or less consolidated portions of the original magma, which were carried up and included in the injected magmas.

The true segregation veins and patches in the diorite-gabbro are undoubtedly the final products of consolidation of the magma in place, and probably many of the aplite veins and dykes have been formed in a similar manner from the granodiorite; the origin of the later porphyrite and basaltic dykes is more obscure, and no satisfactory explanation is offered for their occurrence.

This interpretation of the plutonic differentiation seems to be in accordance with the main facts, explaining as it does (i) that the chief types are members of a continuous series produced by serial differentiation, and that they are really evidences of the composition of the liquid part of the magma at certain stages in its history; (ii) the normal order of decreasing basicity in the intrusion of the main types; (iii) the relatively uniform composition of the individual types, which were injected during short periods of diastrophism; (iv) the gaps in the series, which represent periods of quiescence, when differentiation was proceeding without interruption in the intercrustal reservoir; (v) the shape of the batholith, elongated in the direction of crustal weakness; and (vi) the occurrence in neighbouring localities of granite of the same character as that in the batholith, as earth movements probably caused relief of pressure and opportunity for the injection of magma of uniform composition over a considerable area at about the same time.

(vi.) *Age of the Intrusion.*

There is no conclusive evidence in the Moruya district with regard to the age of the intrusion. The batholith intrudes rocks which are either Ordovician or

Silurian in age, and is partly covered by Tertiary beds. The faulting in a direction parallel to the longer axis of the Moruya batholith, which has been recorded by Dr. Jensen as occurring near Sassafras, probably belongs to the same orogenic period, that is, between the deposition of the Devonian sediments and the overlying Permo-Carboniferous strata.

It was considered by Anderson (1892, p. 164) that the intrusion of plutonic rocks of the South Coast, including those at Moruya, which he describes, "probably dates between the Upper Silurian and the deposition of the Devonian conglomerates, the exact position of which in the Devonian Series has not yet been worked out". No specific evidence is brought forward in support of this statement, and the Devonian age of these conglomerates is unproven.

A comparison with the granitic series in other parts of Eastern Australia may be of advantage in attempting to determine the age of the South Coast Intrusives.

In New South Wales little detailed work has been published on the granites of the State. Süssmilch (1914) has given a summary of our knowledge of these igneous rocks. Dealing with the earlier Palaeozoic intrusions he states, "Acid plutonic rocks are extensively developed over the southern and central tableland areas of N.S.W. Many of these intrude strata of Upper Devonian age and belong, therefore, to the Kanimbla Epoch: none are younger, some are probably older".

In the New England district, the plutonic complex described by Mr. Andrews, was injected in later Palaeozoic time, commencing in the Carboniferous, and continuing until Permo-Carboniferous time.

At Mt. Macedon in Victoria, there is another series, also very similar to that at Moruya, which has been described by Skeats and Summers (1912, p. 55) as a "Devonian sub-alkali province". It does not seem improbable that more detailed work on the intrusive rocks of the South Coast will show their close relationship with the Palaeozoic intrusions of Victoria, with regard both to the composition of the original magma and to the age of the intrusions.

In Queensland, the major intrusions of Palaeozoic granite, such as that at Stanthorpe, are considered to be of Permian or Permo-Carboniferous age.

The trend of evidence, therefore, is that granitic intrusions took place in Victoria during the Devonian period, the active front of invasion advancing like a wave in a northerly or north-easterly direction into New South Wales towards the close of the Devonian, and into New England in Carboniferous time, reaching Queensland during the Permian or Permo-Carboniferous period. This idea has been expressed diagrammatically by Professor Benson (1923, p. 15).

Hence, it is highly probable that the intrusion at Moruya is no exception to the general rule as stated by Mr. Süssmilch for the central and southern tablelands, and that its injection most probably took place in late Devonian time, during the Kanimbla Epoch.

(5) The Metamorphic Series.

Two periods of metamorphism have left their impress on the older sediments of the area under consideration.

The earlier period was one of regional metamorphism, which affected a large part of the central and southern tablelands and south coast of New South Wales. In this metamorphism the main factor was lateral pressure, apparently from the east, which produced meridional folding and faulting of the fine-grained argillaceous and arenaceous sediments of the Moruya district. The rocks were hardened and compacted to form slates, phyllites and quartzites, without appreciable recrystallization of the constituent minerals. Vertical meridional cleavage was developed throughout the area, the planes of cleavage frequently cutting across the bedding planes of the folded sediments. The almost entire lack of fossil organisms throughout the series is undoubtedly due to this metamorphism, which has obliterated all traces of the finer structures likely to occur in argillaceous sediments.

By analogy with other parts of the State it seems probable that this metamorphism took place at the close of the Silurian period.

Superimposed on this metamorphism is a phase of local or contact metamorphism, the direct result of the intrusion of the composite batholith. The effect of this phase is expressed in a zone of recrystallized rocks bordering the batholith, the width of outcrop of the aureole being approximately half a mile. The batholith is transgressive, cutting across the planes of bedding and cleavage of the country rock. As far as could be ascertained, the schistosity, commonly produced by the development of flakes of mica arranged in parallel orientation, is not parallel to the bounding surface of the batholith, but is parallel to the bedding of the original sediments from which the metamorphic rocks were derived. Thus it seems that heat rather than pressure was the dominant factor in this phase of contact metamorphism.

It was not found possible to distinguish exactly the effect on the sediments of the successive injections of magma, nor was it possible to map concentric zones of metamorphism. The rocks are of the nature of schists and hornfelses and have been derived from three main types:

(i) Arenaceous sediments,
(ii) Argillaceous sediments,
(iii) Basic igneous rocks.

No calcareous rocks are known to occur in the district.

(i). Arenaceous sediments.—The purest siliceous rock of sedimentary origin occurs in the Government quarry about a quarter of a mile east of the granodiorite contact on the northern bank of the Moruya River. This rock has been used in the building of the breakwater and training wall near the mouth of the river. Somewhat similar rock occurs, in bands, through the quarry at Yarragee.

The rock is very hard, fine-grained, dark grey and traversed by narrow veins of white quartz. It consists of angular fragments of quartz, less than 0·5 mm. in diameter, set in a matrix of microcrystalline quartz, with small amounts of biotite, muscovite and iron ore, the latter material being obviously recrystallized cement.

The rock is a quartz-hornfels.

More common varieties are those which have contained argillaceous or felspathic material as a cement for the quartz grains.

These rocks outcrop in the southern portion of Tuross Peninsula, at Du Ross Head (Mullimburra Head), on the main road a mile north of Coila, and at intervals along the western boundary, as well as on the main road five miles north of Moruya. They have been completely recrystallized to form fine-grained schists, which vary in colour from buff to brown or dark grey. It is the development of tiny flakes of mica arranged in parallel orientation, which gives the rock its schistose appearance. Under the microscope, it is seen to consist chiefly of irregular grains of quartz elongated in the direction of schistosity, with occasional orthoclase and somewhat abundant reddish-brown biotite and a smaller amount of muscovite. These rocks may be described as quartz-mica-schists (Plate xviii, fig. 6).

(ii). Argillaceous sediments have produced a variety of metamorphic types, which are exposed over the greater part of the aureole, the best outcrops being along the western boundary of the intrusion. Certain bands close to the contact have produced rocks containing the mineral cordierite, which is not developed in parts remote from the intrusion. A fresh exposure of cordierite-hornfels occurs in contact with a granitic dyke in the quarry at Yarragee, a couple of miles west of the town of Moruya. This is a dense dark blue rock, with a slightly resinous lustre. Under the microscope it shows poikiloblastic structure, the ground fabric consisting of xenoblasts of cordierite 2 mm. or more in diameter, crowded with tiny idioblasts of reddish-brown mica, muscovite and possibly quartz, producing a kind of sieve structure. A photograph of this rock appears on Plate xvii, fig. 5.

More remote from the contact are the "spotted schists"; as the contact is approached these "spots" give place to "knots" of varying dimensions, which are set in a very micaceous matrix of a dark grey to light greenish-grey colour. In places where the original bedding has been preserved, it may be seen that the "knots" attain greater development and greater abundance in some of the original layers than in others adjacent, showing that the original composition had a direct influence on their formation. The "knots" vary from a fraction of a millimetre to nearly one centimetre in length, and the habit is prismatic, suggesting that the mineral is andalusite. Under the microscope, however, no definite andalusite can be seen; the "knots" or porphyroblasts consist of fine-grained "shimmer aggregates", which once may have been either andalusite or cordierite. They sometimes contain patches of isotropic material. The ground fabric is lepidoblastic and exceedingly fine-grained.

(iii). A kind of hornblende-schist, evidently a metamorphosed igneous rock, outcrops near the headland north of Kelly's Point, known locally as "The Clear Hill". The outcrop is surrounded on the landward side by the igneous rocks of the Moruya complex. At the base of the cliff-face, the tonalite is seen to underlie this rock and to send up fine apophyses through it. From its mode of occurrence, therefore, it is impossible to determine whether it was interbedded with the older sedimentary series, or whether it was an early-formed member of the plutonic complex, which has been metamorphosed by subsequent intrusions.

(6) Tectonic History of the Area.

The older sedimentary rocks of the area are folded about axes which trend almost due north and south. Faulting and cleavage are also developed in this direction, giving the grain of the country a decided north and south trend. The intensity of the folding appears to have been greater in the east than in the west, and the faulting has been accompanied by the intrusion of massive quartz-porphyry. The dips of the faults are usually very steep, almost vertical, but occasionally (along the course of the Deua) the faults dip at low angles to the east with overthrusting from the direction of the Tasman Sea.

The intrusion of the Moruya batholith took place at a later date along a zone of weakness, probably of faulting, extending in a north-north-westerly direction. Not only do the mapped boundaries of the batholith conform with this direction, but also the internal structures of the batholith, the parallel arrangement of the minerals and inclusions, the rift and grain structures, and the directions of the joints and dykes in the granodiorite, all indicate a change in the direction of the trend lines from north and south to north-north-west and south-south-east.

The disposition of the joint and dyke systems within the batholith itself seems to agree with the ideas put forward by Cloos (1922; 1923) as interpreted by Tyrrell (1926) and Kemp (1925).

In describing the tectonic history of New South Wales in 1914, Professor David states: "In the Bathurst-Monaro Tableland the old trend lines are still shown by the direction of outcrop of the chief beds of limestone of Silurian age, which there run north and south. Towards the northern edge of the plateau these fold lines swing round more west of north, the chief synclinal troughs in the Upper Devonian series lying along directions between north-north-west and north 30° west. . . In the Yass district the general trend of the folds in Silurian and also Devonian rocks is north 15° west and south 15° east". In the New England district the "Carboniferous and Devonian rocks have been folded and powerfully fractured along this north-north-west and south-south-east tectonic zone".

This later trend at Moruya is therefore not an unusual one for New South Wales, although it is not so important as in Queensland, where, according to Bryan (1925), "This N.N.W. trend is all important in the structural geology". Elsewhere (p. 21) he states "The N.N.W. trend . . . seems everywhere to be later than the Devonian period, and may be in part Post-Carboniferous".

The effects of the older north and south trend and the newer north-north-west and south-south-east trend at Moruya are apparent in the physiography of the district, and will be discussed in a later paper.

(7) SUMMARY.

The paper includes a geological sketch-map of the Moruya district, covering an area of about 100 square miles, with an account of the Palaeozoic geology of this area and of other places of interest within a radius of about 25 miles of Moruya.

The salient features in the Palaeozoic geology are (1) the deposition of a series of argillaceous and fine-grained arenaceous sediments during the Ordovician or the Silurian period; (2) the subsequent folding and faulting of these sediments in a meridional direction during a period of regional metamorphism, which probably dates to the close of the Silurian; (3) the alteration in the trend lines to a north-north-westerly and south-south-easterly direction, and the injection of a plutonic igneous mass along a zone of weakness in this direction, probably at the close of Devonian time.

The plutonic mass takes the form of a composite batholith, and forms a complete subalkaline or calcic igneous complex, as is proved by a study of the field-relationships, and the mineralogical and chemical compositions of the various members of the series. The complex consists of three main plutonic types, diorite-gabbro, tonalite-granodiorite and biotite-granite, containing accidental and cognate xenoliths in some parts, and a series of dyke rocks ranging from aplitic to basaltic varieties. Magmatic differentiation of a serial nature probably took place in an intercrustal reservoir by means of fractional crystallization and the sinking of crystals, the liquid portion of the magma being injected at various stages into the upper layers of the earth's crust, and producing an order of decreasing basicity and increasing alkalinity in the intrusion of the plutonic types.

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EXPLANATION OF PLATES XV-XVIII.

Plate xv.

Geological Sketch map of the Moruya District.

Plate xvi.

1. Folded, thin-bedded quartzites, about one and a half miles south-west of Moruya. This is portion of a mass of sedimentary rocks which appears to have been rifted off the magma-chamber (see p. 184).
2. View at Kelly's Point, showing jointing of the tonalite and diorite-gabbro, and its influence on the direction of the basaltic dykes.

Plate xvii.

1. Biotite-Granite, N.W. of Moruya, showing orthoclase with microperthite. Crossed nicols. Magnified 12 diameters.
2. Granodiorite, quarry, 2 miles east of Moruya. Note fracture and granulation. Crossed nicols. Magnified 9 diameters.
3. Fine-grained Granodiorite, 1 mile S.W. of Moruya, showing rounded grains of quartz included in outer zones of plagioclase phenocrysts. Crossed nicols. Magnified 12 diameters.
4. Basic Inclusion in Granodiorite, showing large plate of biotite with inclusions of felspar. Ordinary light. Magnified 9 diameters.
5. Gabbro, north of Kelly's Point, showing large crystal of brown hornblende containing remnants of original augite; border consists of green hornblende. Crossed nicols. Magnified 13 diameters.
6. Typical Gabbro, Kelly's Point, showing brown hornblende (dark) bordered by green hornblende (lighter); Plagioclase appears white. Ordinary light. Magnified 9 diameters.

Plate xviii.

1. Plagioclase in graphic intergrowth with augite, hornblende and iron-ore, in Diorite-gabbro, Kelly's Point. Crossed nicols. Magnified 9 diameters.
2. Portion of the above Plagioclase showing details of graphic intergrowth. Crossed nicols. Magnified 14 diameters.
3. Hornblende-quartz-Porphyrite, Dyke, Tuross, showing granophyric structure in the groundmass. Crossed nicols. Magnified 16 diameters.
4. Mica-Lamprophyre, Lake Coila. Ordinary light. Magnified 12 diameters.
5. Cordierite-Hornfels, Yarragee. Crossed nicols. Magnified 13 diameters.
6. Quartz-mica-Schist, Yarragee. Crossed nicols. Magnified 13 diameters.